



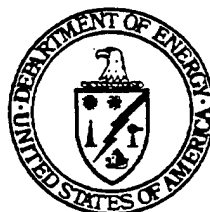
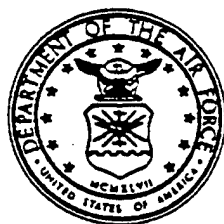
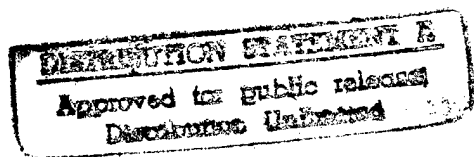
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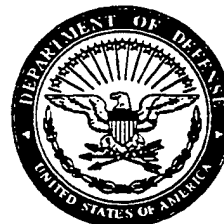
October 1993

Synopses of Federal Demonstrations of Innovative Site Remediation Technologies

Third Edition



*Federal
Remediation
Technologies
Roundtable*



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Prepared by the

**Member Agencies of the
Federal Remediation Technologies Roundtable**



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Third Edition

Prepared by the Member Agencies of the
Federal Remediation Technologies Roundtable:

U.S. Environmental Protection Agency
Department of Defense
 U.S. Air Force
 U.S. Army
 U.S. Navy
Department of Energy
Department of Interior

1993

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NOTICE

The information in this document has been funded wholly by the United States Environmental Protection Agency under Contract 68-W2-004. It has been subject to administrative review by all agencies participating in the Federal Remediation Technologies Roundtable, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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NOTE: Abstracts marked with an asterisk (*) are appearing for the first time in this edition.

PREFACE

This collection of abstracts, compiled by the Federal Remediation Technologies Roundtable, describes field demonstrations of innovative technologies to treat hazardous waste at contaminated sites. This document updates and expands information presented in the second edition of the collection which was published in 1992. An asterisk (*) in the Table of Contents marks synopses appearing for the first time in this edition.

The collection is intended to be an information resource for hazardous waste site project managers for assessing the availability and viability of innovative technologies for treating contaminated ground water, soils, and sludge. It also is intended to assist government agencies in coordinating ongoing hazardous waste remediation technology research initiatives, particularly those sponsored by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DOD), the U.S. Department of Energy (DOE), and the U.S. Department of Interior (DOI). Innovative technologies, for the purposes of this compendium, are defined as those for which detailed performance and cost data are not readily available.

The demonstrations contained herein have all been sponsored by EPA, DOD, DOE, and DOI. In total, 112 demonstrations in six different technology categories are described. These demonstrations involve the use of innovative technologies to treat soil and ground water. A matrix listing the demonstration categories, the type of contaminant, media that can be treated, and the treatment setting for innovative technologies demonstrated is provided in Exhibit 1 on page xii. Although descriptions of demonstrations involving more conventional treatment technologies, such as incineration and solidification, do not appear in the main body of this edition, a selection of abstracts on these technologies has been included in Appendix A for your information.

The synopses contained in this document focus on specific demonstration projects. However, Appendix B describes more general demonstration programs being undertaken by the U.S. Air Force and the Departments of Energy and Interior.

Finally, Appendix C provides technology contacts in the agencies that have such points for public access. These contacts provide a starting point for those wishing to access or learn more about individual Federal technology programs.

This document represents a first step in the review of treatment technologies available for application to hazardous waste sites. This compendium should not be looked upon as the sole source for this information — it does not include all innovative technologies or all technology demonstrations performed by these agencies. Only Federally-sponsored studies and demonstrations that have tested innovative remedial technologies with site-specific wastes under realistic conditions as a part of large pilot- or full-scale field demonstrations are included. These studies represent all that were provided to the Federal Remediation Technologies Roundtable at the time of publication. Information collection efforts are ongoing.

The Federal Remediation Technologies Roundtable

This publication was prepared under the auspices of the Federal Remediation Technologies Roundtable (Roundtable). This organization was created to establish a process for applied hazardous waste site remediation technology information exchange, to consider cooperative efforts of mutual interest, and to develop strategies and analyze remedial problems that will benefit from the application of innovative technologies. The Roundtable is comprised of representatives from several Federal agencies:

U.S. Environmental Protection Agency, Technology Innovation Office (EPA/TIO)

The mission of the Technology Innovation Office (TIO) is to increase applications of innovative treatment technology by government and industry to contaminated waste sites, soils, and ground water. TIO intends to increase usage of innovative techniques by removing regulatory and institutional impediments and providing richer technology and market information to targeted audiences of Federal agencies, States, consulting engineering firms, responsible parties, technology developers, and the investment community. The scope of the mission extends to Superfund sites, corrective action sites under the Resource Conservation and Recovery Act (RCRA), and underground storage tank cleanups. By contrast, TIO is not a focus for EPA interest in treatment technologies for industrial or municipal waste streams, for recycling, or for waste minimization. The Director of EPA/TIO serves as the chairperson for the Roundtable.

U.S. Environmental Protection Agency, Office of Research and Development (EPA/ORD)

The Office of Research and Development oversees EPA's Superfund Innovative Technology Evaluation (SITE) program. This program supports development of technologies for assessing and treating waste from Superfund sites. The SITE program was authorized by the Superfund Amendments and Reauthorization Act of 1986 with the goal of identifying technologies, other than land disposal, that are suitable for treating Superfund wastes. The program provides an opportunity for technology developers to demonstrate their technology's capability to successfully process and remediate Superfund waste. EPA evaluates the technology and provides an assessment of potential for future use for Superfund cleanup actions. The SITE program has currently evaluated or supported research efforts for about 146 innovative treatment technologies. The SITE program is administered by EPA's Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio.

U.S. Department of Defense (DOD), Defense Environmental Restoration Program (DERP)

The Office of the Secretary of Defense (OSD), operating through the Deputy Assistant Secretary of Defense, Environment (DASD (E)), establishes policy and monitors the Armed Forces' execution of the DOD hazardous waste site clean-up program. The Defense Environmental Restoration Program (DERP) funds activities at over 17,000 DOD sites located on nearly 1,700 properties through the Installation Restoration Program (IRP). The DOD works cooperatively with the Environmental Protection Agency and the States toward the goal of taking timely, effective, and efficient actions at all stages of the DERP. Research and development of better methods for site

investigation and cleanup is an important part of DERP. Many innovative technologies have been developed and demonstrated to improve the speed and cost-effectiveness of DOD site cleanups.

U.S. Air Force Civil Engineering and Support Agency (AFCESA)

The Air Force Civil Engineering and Support Agency (AFCESA) is responsible for identifying, developing, and testing technologies that may be useful for remediating contaminated sites as part of the Air Force's Installation Remediation Program.

U.S. Army Corps of Engineers

In support of the Army's Installation Restoration (IR) Program, the U.S. Army Corps of Engineers has the responsibility of ensuring the development of necessary and improved technology for conduct of the Program. The U.S. Army Corps of Engineers is also charged with the responsibility for developing improved pollution abatement and environmental control technology in support of the U.S. Army Material Command industrial complex (Pollution Abatement or PAECT Program). The purpose of the IR Decontamination Development Program is to provide R&D support to required assessment and clean-up actions at Army installations. Efforts include evaluating commercially available state-of-the-art technologies as well as developing new, innovative technologies that are more economical and efficient than existing technology. The PAECT program addresses waste minimization and disposal alternatives for the Army's industrial operations.

U.S. Army Environmental Center (formerly U.S. Army Toxic and Hazardous Materials Agency)

The U.S. Army Environmental Center (USAEC) is a major focal point in the program management and support efforts of the Army-wide environmental program. With its principal focus directed toward supporting the installation in achieving and maintaining environmental compliance, the Center's activities fall into five major categories:

- Environmental Compliance;
- Installation Restoration Program (IRP);
- Environmental Training and Awareness;
- Research and Development (R & D); and
- Environmental Information Management.

U.S. Navy, Naval Civil Engineering Laboratory (NCEL)

The Naval Civil Engineering Laboratory (NCEL) develops technologies for restoration efforts at Navy and Marine Corps Installations. NCEL serves as a consultant to project managers at Navy restoration sites, planning and conducting applied research and demonstration projects to support restoration objectives.

U.S. Department of Energy (DOE), Office of Environmental Restoration

The Department of Energy (DOE) is faced with the largest environmental clean-up task ever to confront the United States Government. The primary objectives of DOE's Environmental Restoration (ER) Program are to stabilize radioactive waste or perform decontamination and decommissioning at contaminated DOE and legislatively authorized non-government installations and sites; conduct assessments and characterization of DOE sites to determine if there is the potential for radioactive and hazardous waste releases; and to protect human health and the environment. The goal of the Environmental Restoration Program is the cleanup of contaminated DOE and legislatively authorized sites within 30 years.

U.S. Department of Energy (DOE), Office of Technology Development

DOE's Office of Technology Development was established to identify technologies in the research and development and demonstration (RD&D) stage, and to demonstrate, test, and evaluate those technologies that will provide DOE with accelerated and/or improved methods for achieving its environmental goals as specified in its Five-Year Plan.

U.S. Department of Interior (DOI)

As the principal conservator of the Nation's public lands and natural resources, the Department of Interior (DOI) has three primary areas of waste management concern: abandoned mine sites; illegal dumping on Federal lands; and landfills that were leased to counties and municipalities. DOI manages wastes to safeguard resource values and to protect the lives and health of the millions of people who work, live, and recreate on lands managed by DOI. The Bureau of Mines, the Bureau of Reclamation, and the Geological Survey are the primary agencies within DOI who provide technical consultation and research assistance to DOI and other Federal agencies for solution of waste management problems. For example, extensive research conducted by the nine research laboratories of the Bureau of Mines is directly applicable to the management of mining and mineral waste problems. This consultation and research effort has been extended to encompass the cost-effective treatment of other inorganic wastes.

Future Demonstrations

This publication will be updated on a periodic basis. If you will be conducting a demonstration featuring an innovative hazardous waste treatment technology in the future, or if you are aware of a project that is relevant to this collection but has been omitted, please forward this information to EPA/TIO:

Daniel M. Powell
Technology Innovation Office
U.S. Environmental Protection Agency
401 M Street, SW, 5102W
Washington, DC 20460

For your convenience, we have included, at the end of this volume, the Innovative Remedial Technologies Information Collection Guide to assist you in formatting the information for inclusion in this compendium. The Roundtable developed this guide as a model for use in collecting findings on innovative technologies and their applications, effectiveness, and costs.

The guide is intended to facilitate new data collection efforts, and it indicates the data we are most interested in capturing. If, however, you have already collected and recorded the information in an alternative format, please feel free to forward any previously written abstract or summary. We will reformat it to be included in this compendium.

If you have any comments on the usefulness and clarity of this publication, please complete the suggestion form on the last page, and send it to Daniel Powell.

Exhibit 1

Matrix Showing the Various Combinations of
Technology/Contaminant/Media/Treatment Type Addressed in this Edition

Innovative Technology	Contaminant										Media		Treatment Setting		Page
	Halogenated volatiles and semivolatiles	Nonhalogenated volatiles and semivolatiles	PCBs	Pesticides	Cyanides	Metals	Radioactive Materials	Explosives	Surface Water	Groundwater	Soils	Sludges	In Situ	Ex Situ	
Bioremediation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1
Chemical Treatment	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	59
Thermal Treatment	✓	✓	✓	✓		✓	✓	✓			✓	✓	✓	✓	77
Vapor Extraction	✓	✓				✓				✓	✓	✓	✓	✓	117
Soil Washing	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	147
Other Physical Treatment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	181

BIOREMEDIATION



Aerated Static Pile Composting Explosives (TNT, RDX, HMX) in Lagoon Sediments

Technology Description

Composting is a process by which organic materials are biodegraded by microorganisms, resulting in the production of organic and inorganic by-products and energy in the form of heat. This heat is trapped within the compost matrix, leading to the self-heating phenomenon known as composting. Composting is initiated by mixing biodegradable organic matter (explosives in this study), with organic carbon sources and bulking agents, which are added to enhance the porosity of the mixture to be composted.

In "static pile" composting, an aeration/heat removal system is utilized to increase process control over the composting system. The aeration/heat removal system typically takes the form of a network of perforated pipe underlying the compost pile. The pipe is attached to a mechanical blower and air is periodically drawn or forced through the compost to effect aeration and heat removal.

The composting test facilities were constructed of concrete test pads with runoff collection systems and sumps, covered by a roof to protect the compost piles from weather and to minimize the amount of moisture collected in the sump. Bulking agents and carbon sources consisted of horse manure, alfalfa, straw, fertilizer, and horse feed. Baled straw was used to contain the pile contents, and was arranged in a ring around the perimeter of each pile. Sawdust and hardwood mulch were used to construct the pile bases, provide additional bulking material, and insulate the piles. After mixing, the compost was

transported to the composting pads. Each compost pile contained a system of pipes connected to a blower, as described above. A cross-sectional schematic diagram of a compost pile is provided.

Technology Performance

The primary objective of this study was to evaluate the utility of aerated static pile composting as a technology for remediating soils and sediments contaminated with the explosives TNT, HMX, RDX, and tetryl.

Secondary objectives included evaluating the efficacy of thermophilic (55°C) versus mesophilic (35°C) composting, evaluating different materials handling and process control strategies, and determining transformation products when Standard Analytical Reference Materials (SARMs) were available.

Temperature was the primary test variable investigated. The temperature of one set of compost piles was kept within the mesophilic range; the temperature of the second set of piles was kept in the thermophilic range. The initial concentration of explosives in test sediments collected from the lagoon was 17,000 mg/kg. Phase I (piles 1 and 2) was conducted with a mixture of lagoon sediments, sawdust, wood chips, and a straw/manure mixture. Based on data received from phase I, phase II (piles 3 and 4) added alfalfa and horse feed to the compost mixture to increase the concentration of biodegradable organic carbon in the compost mixture. After 153 days of composting, the

solvent-extractable total explosives were reduced to 376 mg/kg and 74 mg/kg in the mesophilic and thermophilic piles, respectively. The mean percent reductions of extractable TNT, RDX and HMX were 99.6, 94.8, and 86.9 weight-percent in the mesophilic piles, and 99.9, 99.1, and 95.6 weight-percent in the thermophilic piles.

The results of this field demonstration indicate that composting is a feasible technology for decontaminating explosives-contaminated soils and sediments. Further investigation is warranted for optimizing the materials balance and soil loading rate for mixtures to be composted, minimizing bulking agent used, and developing a design and operation management plan for a full-scale composting facility. In addition, the compost residue should be subjected to a toxicity evaluation and more extensively analyzed to determine the final fates of HMX, RDX, TNT, and tetryl.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This field-scale demonstration project was conducted at the Louisiana Army Ammunitions Plant (LAAP). Compost piles were constructed and tested at LAAP between December 1987 and April 1988. Phase I piles were tested for 33 days; phase II piles were tested for 153 days. Approximately 21 cubic yards of sediment was excavated from Pink Water Lagoon No. 4 for use in this study.

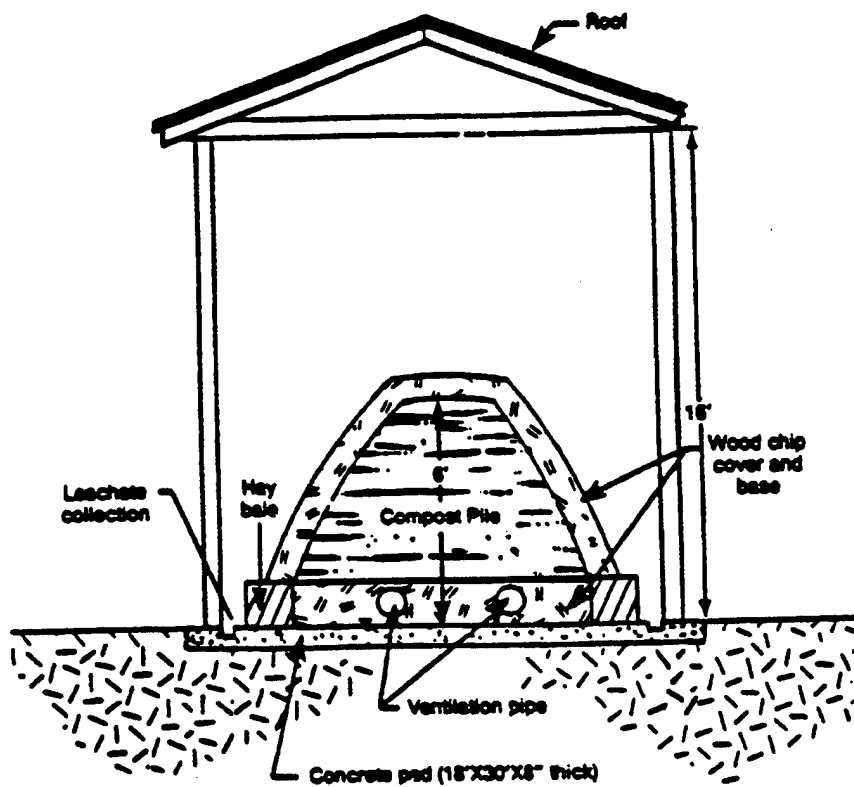
LAAP was built to load and pack ordnance for the U.S. Army. Explosives have never been manufactured at the facility, but are brought in and utilized in loading, assembling, and packing lines. Initially, the area where the field demonstration was conducted was used as a burning grounds to dispose of out-of-

specification ordnance. These burning pits were converted to lagoons in the mid-1940s. The lagoons were used to dispose of wastewater generated during wash-down of the munitions loading lines. Equipment used to load munitions was washed with water, and the resulting wastewater contained high concentrations of suspended explosives ("pink water"). Pink water was transported to the unlined lagoons and dumped into individual lagoons via a concrete spillway. Suspended explosives settled to the bottom of the lagoons. Over the period of approximately 30 years, during which pink water was disposed of in the lagoons, high concentrations of explosives accumulated in the upper sediment. The highest concentrations (300,000 to 600,000 mg/kg) accumulated near the spillways. In October, 1984, the pink-water lagoon site at LAAP was proposed for inclusion on the National Priority List (NPL).

Contacts

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Peter J. Marks — Project Manager
Roy F. Weston, Inc.
One Weston Way
West Chester, PA 19380



Aerated Static Pile Composting of Explosives



Aerated Static Pile Composting Propellants (Nitrocellulose) in Soil and Sediments

Technology Description

Composting is a process by which organic materials are biodegraded by microorganisms, resulting in the production of organic and inorganic by-products and energy in the form of heat. This heat is trapped within the compost matrix, leading to the self-heating phenomenon known as composting. Composting is initiated by mixing biodegradable organic matter (nitrocellulose (NC) in this study) with organic carbon sources and bulking agents, which are added to enhance the porosity of the mixture to be composted.

In "static pile" composting, an aeration/heat removal system is utilized to increase process control over the composting system. The aeration/heat removal system typically takes the form of a network of perforated pipe underlying the compost pile. The pipe is attached to a mechanical blower and air is periodically drawn or forced through the compost to effect aeration and heat removal. The primary objective of hazardous materials composting is to convert hazardous substances into innocuous products for ultimate disposal, such as land application.

The composting test facilities were constructed of concrete test pads with runoff collection systems and sumps, covered by a roof to protect the compost piles from weather and to minimize the amount of moisture collected in the sump. Bulking agents and carbon sources consisted of a cow manure slurry, alfalfa, straw, and horse feed. Baled straw was used to contain the pile contents, and was arranged in a ring around the perimeter of each pile. Sawdust and hardwood

mulch were used to construct the pile bases, provide additional bulking material, and insulate the piles. After mixing, the compost was transported to the composting pads. Each compost pile contained a system of perforated and non-perforated pipes connected to a blower. The blowers were used to pull air through the compost piles to promote aeration and remove excess heat. A cross-sectional schematic diagram of a compost pile is provided.

Technology Performance

The primary objective of this study was to evaluate the utility of aerated static pile composting as a technology for NC fine (out-of-specification NC) remediation and destruction of soils contaminated with NC. Secondary objectives included evaluating the efficacy of thermophilic (55°C) versus mesophilic (35°C) composting, determining a maximum soil loading rate, and comparing different process control and material handling strategies.

The test variable in compost piles 1 and 2 (phase I) was temperature. The temperature of pile 1 was kept within the mesophilic range, and the temperature of pile 2 was kept in the thermophilic range. The concentration of NC in test soils collected from the dredge basin were 18,800 mg/kg for phase I tests. After mixing, total NC concentration in pile 1 was 3,670 mg/kg, and concentration in pile 2 was 3,608 mg/kg. After 152 days of the study, mean total NC concentrations were 651 mg/kg and 54 mg/kg, respectively. Information concerning the effect of temperature on the NC concentration

was inconclusive, however, because there were apparent discrepancies in the starting data gathered for pile 1.

The test variable in piles 3 and 4 (phase II) was the degree of soil loading within each pile. The initial soil loading was increased from 19 percent in piles 1 and 2 to 22 percent in pile 3, and 32.5 percent in pile 4. The concentration of NC in tests soils collected for phase II was 17,027 mg/kg. After mixing, the concentration of NC in pile 3 was 7,907 mg/kg, and 13,086 mg/kg in pile 4. After 112 days of the study, total mean concentrations of NC were 30 mg/kg and 16 mg/kg, respectively. Both piles showed greater than 99.5 percent reduction of NC from the starting point of the test. These results suggest that successful composting likely will occur at sediment loading rates of up to 50 percent or exceeding 50 weight-percent.

The results of this field demonstration indicate that composting is a feasible technology for reducing the extractable NC concentration in contaminated soils. In addition, this study provides tentative evidence indicating that NC can be degraded when incorporated into a mixture to be composted at a high concentration.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This field-scale demonstration project was conducted at the Badger Army Ammunitions Plant (BAAP) in Sauk County, Wisconsin. Four compost piles were constructed at BAAP during the period from April, 1988, to January, 1989. The first set of compost piles was tested

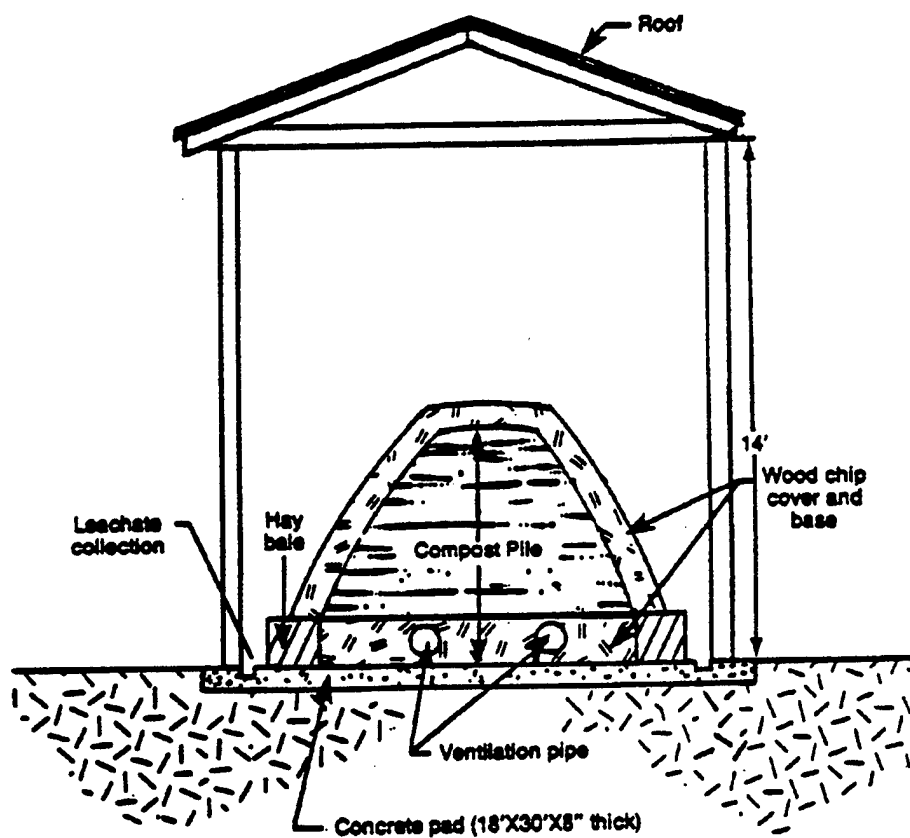
for 151 days; the second set was tested for 112 days. Approximately 13 cubic yards of test soils were excavated from Dredge Spoil Basin No. 1 for use in this study.

Constructed in 1942, the plant operated intermittently over a 33-year period, producing single- and double-base propellants for rocket, cannon, and small arms ammunition. During the plant's period of active operation, various chemical materials were produced, and the associated wastes and manufacturing by-products were disposed on-site. The wastes included acids, nitroglycerin, and NC. As a result of the disposal practices, contamination of soils, the underlying aquifer, and, to some extent, surface waters has occurred.

Contacts

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Roy F. Weston, Inc.
One Weston Way
West Chester, PA 19380



Aerated Static Pile Composting of Propellants



Aerobic Biodegradation TCE and PCE in Ground Water

Technology Description

In this treatment, ground water from a contaminated aquifer is pumped to a methanotrophic fluidized bed or trickle filter bioreactor. Target contaminants, TCE and perchloroethylene (PCE) at 1,000 parts per billion (ppb), are aerobically degraded. A 90 percent removal efficiency can be achieved with this process. However, aquifers that are not homogeneous and/or contain large clayey zones will not allow end-point concentrations to be achieved for very long times. Waters high in copper also may inhibit the process.

Technology Performance

This process has been demonstrated successfully at a nuclear production pilot-scale testing facility at the U.S. Department of Energy's (DOE) Savannah River Site. The current pilot-scale system has a treatment capacity of 5 gallons per minute (gpm). No preliminary or secondary treatment is required. Residuals—excess biomass—of less than 1 lb/day are produced.

Remediation Costs

Cost for using this process is estimated at \$0.50/gallon (gal). Approximately 3 months is required for design of the system. Routine operation and maintenance require about 8 hours (hr)/week.

General Site Information

This aerobic biodegradation process was tested at a nuclear production pilot-scale testing facility at the Savannah River Site located near Aiken, SC.

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Aerobic Composting Optimization

Explosives (TNT, RDX, HMX) in Contaminated Soil and Sediment

Technology Description

Composting is a controlled biological process by which biodegradable materials are converted by microorganisms to innocuous, stabilized by-products. In most cases, this is achieved by the use of indigenous microorganisms. Explosives-contaminated soils are excavated and mixed with bulking agents, such as wood chips, and organic amendments, such as animal, fruit, and vegetative wastes. Maximum degradation efficiency is controlled by maintaining moisture content, Ph, oxygenation, temperature, and the carbon-to-nitrogen ratio. There are three process designs used in composting: aerated static piles; windrowing; and mechanically agitated in-vessel composting. This technology requires substantial space to conduct the composting operation and results in a volumetric increase in material due to the addition of amendment material.

The composting demonstration at Louisiana Army Ammunition Plant (LAAP) demonstrated that aerobic, thermophilic composting is able to reduce the concentration of explosives (TNT, RDX, and HMX) and associated toxicity to acceptable health-based clean-up levels. However, an economic analysis determined that full-scale implementation of composting of explosives-contaminated soils using previously investigated design parameters was not economically competitive with incineration. An optimization field demonstration was initiated at a National Priority List (NPL) site at Umatilla Depot Activity, Hermiston, Oregon, to investigate several process design parameters that would make this technology more cost

effective. In addition, extensive chemical characterization and toxicity studies were conducted on the final composted product.

The primary objective of this study was to increase the quantity of soil processed in a composting treatment system per unit of time. Since soil throughput is dependent on the rates of degradation and the percent soil loading, the key variables investigated in the study were amendment mixture composition and percent contaminated soil loading. In addition, two technologies were evaluated: aerated static pile and mechanically agitated in-vessel composting systems.

Amendment selection was based on adiabatic testing using a combination of fifteen readily available agricultural wastes. The amendments selected and their approximate costs are provided in Table 1. Percent soil loading was investigated using seven 3-cubic-yard aerated static pile systems, which were constructed from fiberglass, to model actual static pile conditions. Different soil amendment ratios and amendment mixture compositions were investigated using a special 7-cubic-yard pilot-scale mechanically agitated in-vessel (MAIV) system constructed according to rigorous explosive safety standards. The MAIV system uses rotating augurs attached to the rotating cover to mix the compost.

The static pile systems and the MAIV system were housed in greenhouses to protect them from the environment and prevent the spreading of contaminated dust. A computer-based data acquisition and control system was used to monitor and regulate the environment in each of

the compost systems. Temperatures were kept from exceeding 55°C using forced aeration and the moisture content was maintained at between 45 and 50 percent. Compost samples were taken at various time intervals, homogenized, and split into two fractions. One fraction was analyzed for the presence of TNT, RDX, and HMX, while the other was tested for toxicity.

Since the implementation of this technology will be based on its ability to meet health-based clean-up criteria, the resultant composted material was subjected to chemical characterization and toxicological evaluation.

Technology Performance

The study confirmed the LAAP composting study results, which indicated that composting can effectively treat TNT-, RDX-, and HMX-contaminated matrices. The study indicated that both static pile and MAIV composting technological approaches are effective in degrading explosives. The percent reduction of explosives observed in the tests are provided in Table 2. Other major findings include the following:

- In the static pile tests, the majority of the degradation occurred in the first 44 days, while the majority of the degradation occurred in the first 10 days in the MAIV tests;
- The amendment composition is an important parameter in achieving maximum reduction of RDX and HMX; the maximum loading level for both appears to be 30 volume percent;
- Mixing is important in achieving rapid and extensive destruction of explosives (A pilot-scale composting windrow demonstration has been initiated as a result of this finding and is scheduled for completion in FY92);
- Chemical characterization and toxicity testing concluded that composting can

effectively reduce the concentrations of explosives and bacterial mutagenicity in contaminated soil and can reduce the aquatic toxicity of leachate compounds.

Additional studies are being sponsored to determine the long-term effectiveness of composting and the nature of the binding of biotransformation products.

Remediation Costs

Costs will vary with the amount of soil to be treated, availability of amendments, type of process design employed, and time allowed to remediate the site. Costs for composting 8,000 tons of explosives-contaminated soils are estimated to be 50 percent less expensive than incinerating the same amount of soil.

General Site Information

Umatilla Depot Activity in Hermiston, Oregon, was selected as the site for this demonstration. Between 1950 and 1965, it was the site of a facility for recovering explosives from unserviceable munitions. The process resulted in large quantities of explosives-contaminated water that was discharged into unlined settling basins. These washout lagoons were placed on the NPL in 1987 because of the presence of explosives in the water-table aquifer. Hand-excavated soils from these lagoons were used in this demonstration.

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Table 1. UMDA Amendment Composition and Approximate Cost

Amendment	Mix		
	A	B	C
Sawdust	30%		22%
Apple pomace	15%		6%
Chicken manure	20%		
Chopped potato	35%		17%
Horse manure/straw		50%	
Buffalo manure		10%	
Alfalfa		32%	22%
Horse feed		8%	
Cow manure			33%
Cost per ton	\$15	\$200	\$11

Table 2. Percent Reduction of Explosives

Test (%soil)	Amendment Mix	Percent Reduction		
		TNT	RDX	HMX
Static Pile:				
0% (Control)	A	n/a	n/a	n/a
7%	A	91	73	39
10%	A	96	46	21
10%	C	99	93	80
20%	A	94	16	5
30%	A	98	22	11
40%	A	79	0	2
Mechanical:				
10%	A	97	90	29
10%	B	99	99	95
25%	C	99	97	68
40%	C	97	18	0

n/a — Uncontaminated soil, no explosives present



Bioremediation

Augmented Subsurface Bioremediation Hydrocarbons in Soil and Water (*In Situ* Treatment)

Technology Description

This process uses a proprietary blend (H-10) of microaerophilic bacteria and micronutrients for subsurface bioremediation of halogenated and non-halogenated hydrocarbons and chlorinated compounds in soil and water. The insertion methodology is adaptable to site-specific situations. The bacteria are hardy and can treat contaminants in a wide temperature range. The process does not require additional oxygen or oxygen-producing compounds, such as hydrogen peroxide. Degradation products include carbon dioxide and water.

The bioremediation process consists of four steps:

- defining and characterizing the contamination plume;
- selecting a site-specific application methodology;
- initiating and propagating the bacterial culture; and
- cleanup monitoring and reporting.

Technology Performance

This technology was accepted into EPA's SITE Demonstration Program in 1991. A demonstration at Williams Air Force Base in Phoenix, AZ, was completed in 1992. The technology failed to meet contracted clean-up standards for JP-4 jet fuel and benzene, toluene, ethylbenzene, and xylenes (BTEX) on two occasions. The developer also has used the process to remediate sites in Illinois and Michigan.

Remediation Costs

Cost information was not provided for this publication.

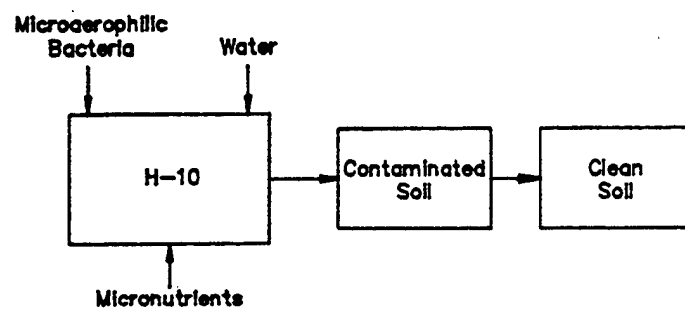
General Site Information

A demonstration of this technology at Williams Air Force Base in Phoenix, AZ, was completed in 1992.

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Augmented In Situ Subsurface Bioremediation Process



Bioremediation

Biodecontamination of Fuel Oil Spills Fuel Oil in Soil (*In Situ* Treatment)

Technology Description

In this treatment, biodegradation is accomplished by applying special oil-degrading bacteria to a bioreactor while filling the reactor with leachate water. As the reactor overflows from a secondary clarifier, bacteria are carried to a spray field sump and to injection wells. Surface sprayers apply the treated leachate water on the spray field while the injection wells apply the treated leachate water to oil spill-contaminated soil under the buildings. As more water is added to the system and the ground under the buildings, the contaminated area becomes saturated. Run-off water, along with leachate water, is collected in a trench down-slope from the contaminated area. The collected water is pumped back to the aerated bioreactor where bacterial growth on the high surface area matrix, on which some of the bacteria are immobilized, occurs. Nutrient and detergent are added to the oxygen-enriched treated leachate water along with bacteria, and it is recirculated to the spray field and injection wells.

Technology Performance

This method was implemented to clean up a fuel oil spill resulting from leaking pipes that connected to #2 diesel fuel storage tanks at a Naval Communication Station at Thurso, Scotland. The microorganisms were found to function best at temperatures between 20°C and 35°C. *Biodecontamination of Fuel Oil Spill Located at NAVCOMMSTA, Thurso, Scotland: A Final Report* was published in Dec. 1985.

Remediation Costs

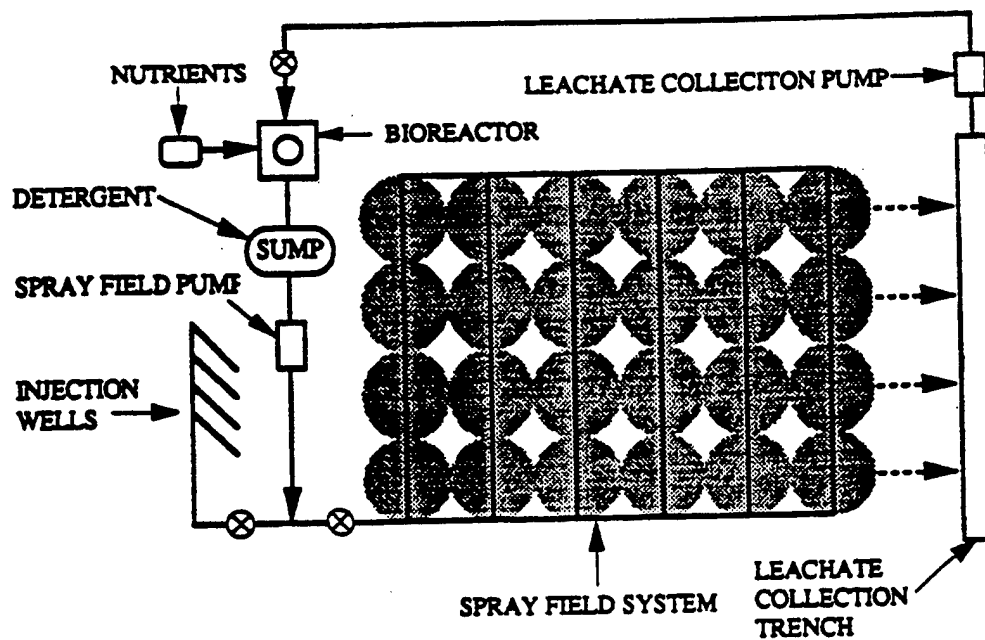
The site was cleaned-up to a satisfactory level for approximately \$37,000, not including shipment of the equipment to the site, installation labor supplied by facility personnel, and analytical costs.

General Site Information

The contaminated area at Naval Communication Station at Thurso, Scotland, had a considerable slope, and the contaminated soil was a thin layer over a relatively impermeable rock substrate. In this case, oil was entrapped in the soil matrix beneath boiler and power buildings, an area approximately 800 m². The project lasted from February to October, 1985.

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Biodecontamination Process



Biodegradation

TCE and PCE in Soil and Ground Water (*In Situ* Treatment)

Technology Description

This process involves injection of 1 to 4 percent methane/air into an aquifer via horizontal wells. This encourages reductive dechlorination of PCE to TCE by anaerobes and stimulates indigenous methanotrophs to oxidize TCE.

High concentrations of copper in the matrix can inhibit the process. In addition, high-clay soils may require longer stimulation.

Technology Performance

This process was demonstrated at DOE's Savannah River Site. Extensive soil and ground water monitoring showed that methanotroph densities increased five orders of magnitude and TCE/PCE declined to less than 2 ppb.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Biodegradation technology was demonstrated at an abandoned seepage basin at the Savannah River Site near Aiken, SC, as part of DOE's ongoing Integrated Demonstration Project. The basin was a disposal area for solvents used for degreasing nuclear fuel target elements.

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Bioremediation

Biodegradation of Lube Oil-Contaminated Soils Motor Oil in Soil (*In Situ* Treatment)

Technology Description

This treatment process requires the addition of inoculant and nutrients to the contaminated soils during diskings. (The nutrients in the pilot studies have consisted of sodium acetate, minerals — potassium, magnesium, ammonium, phosphate, and sulfate ions — and Tween 80, a surfactant.) Afterward, the site is covered with plastic sheeting. The plastic sheeting must have holes to allow the transport of air.

This method is applicable for oil spills at maintenance facilities, air strips, along roadways and streets, and parking lots. Although research on the method has been directed to degradation of used lubrication oil, it should be applicable to almost any non-functionalized aliphatic hydrocarbon.

Technology Performance

A small-scale pilot test has been conducted at the U.S. Army Construction Engineering Laboratory in Champaign, Illinois. Noticeable reduction in contaminant concentrations were

evident after four to six weeks. Pilot plots consisted of plastic tubs containing eight kilograms of contaminated soil placed outside and covered with plastic. Flask tests were conducted initially to identify optimum conditions.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

A small-scale pilot test was conducted at the U.S. Army Construction Engineering Laboratory in Champaign, Illinois.

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BIO-FIX Beads

Metals in Water

Technology Description

Porous polymeric beads containing immobilized biological materials have been developed to extract toxic metals from water. The beads, designated as BIO-FIX beads, are prepared by blending biomass such as sphagnum peat moss or algae into a polymer solution and spraying the mixture into water. The beads have distinct advantages over traditional methods of utilizing biological materials in that they have excellent handling characteristics and can be used in conventional processing equipment or low-maintenance systems. Cadmium, lead, and arsenic are a few of the many metals readily removed by BIO-FIX beads from acid mine drainage (AMD) waters, metallurgical and chemical industry wastewaters, and contaminated ground waters. Because of their affinity for metal ions at very low concentrations, National Drinking Water Standards and other discharge criteria are frequently met. Adsorbed metals are removed from the beads using dilute mineral acids. In many cases, the extracted metals are further concentrated to allow recycle of the metal values.

Technology Performance

Field testing of BIO-FIX bead technology to remove heavy metals from AMD waters has been conducted at four sites. These tests were conducted in cooperation with government agencies and private mining operations. Two of the field tests utilized a standard column system, while the other two tests employed a low-

maintenance circuit developed to treat AMD problems in remote areas. The tests ranged in duration from two weeks to 11 months and more than 200,000 gallons of wastewater were processed. The results were encouraging and indicated that drinking water standards and aquatic wildlife standards could be routinely achieved for copper, cadmium, lead, zinc, manganese, iron, cobalt, and nickel. BIO-FIX beads proved to be chemically and physically stable over repeated loading-elution cycles and were not affected by adverse climatic conditions such as cold temperature or heavy snows.

Remediation Costs

BIO-FIX technology has been licensed from the Bureau of Mines by three environmental remediation companies and is available for commercial application. Cost information will be supplied upon request.

General Site Information

BIO-FIX bead technology has been field tested by the Bureau of Mines at four sites.

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Bioremediation

Biological Aqueous Treatment System **PCP, Creosote Components, Gasoline and Fuel Oil Components,** **Chlorinated Hydrocarbons, Phenolics, and Solvents in Ground Water**

Technology Description

This aqueous treatment system is a patented process that is effective for treating contaminated ground water and process water. The system uses a microbial population indigenous to the wastewater, to which a specific microorganism may be added. This system removes the target contaminants, as well as the naturally occurring background organics.

Contaminated water enters a mix tank, where the pH is adjusted and inorganic nutrients are added. If necessary, the water is heated to an optimum temperature, using both a heater and a heat exchanger to minimize energy costs. The water then flows to the reactor where the contaminants are biodegraded.

The microorganisms that perform the degradation are immobilized in a multiple-cell submerged fixed-film bioreactor. Each cell is filled with a highly porous packing material to which the microbes adhere. For aerobic conditions, air is supplied by fine bubble membrane diffusers mounted at the bottom of each cell. The system may also run under anaerobic conditions.

As the water flows through the bioreactor, the contaminants are degraded to biological end-products, predominantly carbon dioxide and water. The resulting effluent may be discharged to a publicly owned treatment works (POTW) or may be reused on site. In some cases, discharge with a National Pollutant Discharge

Elimination System (NPDES) permit may be possible.

This technology may be applied to a wide variety of wastewaters, including ground water, lagoons, and process water. Contaminants amenable to treatment include pentachlorophenol, creosote components, gasoline and fuel oil components, chlorinated hydrocarbons, phenolics, and solvents. Other potential target waste streams include coal tar residues and organic pesticides. The technology may also be effective for treating certain inorganic compounds such as nitrates; however, this application has not yet been demonstrated. The system does not treat metals.

Technology Performance

During 1986 and 1987, the developer performed a successful 9-month pilot field test of this process at a wood-preserving facility. Since that time, more than 20 full-scale systems have been installed and several pilot-scale demonstrations have been conducted. These systems have successfully treated waters contaminated with gasoline, mineral spirit solvents, phenols, and creosote.

The EPA SITE Program demonstration of this technology took place from July 24 to September 1, 1989, at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. The system was operated continuously for 6 weeks at three different flow rates.

Results of the demonstration indicate that pentachlorophenol (PCP) was reduced to less than 1 part per million (ppm) at all flow rates. Removal percentage was as high as 99 percent at the lowest flow rate. The Applications Analysis Report (EPA/540/A5-91/001) has been published. The Technology Evaluation Report (PB92-110048/AS) is available from the National Technical Information Service (NTIS).

Remediation Costs

According to the EPA Applications Analysis Report, operating cost for this treatment is in the range of \$2.43 to \$3.45/1,000 gal, depending on the system size. Major contributors to cost are labor and heat requirements, with the labor contribution decreasing significantly as the scale increases.

General Site Information

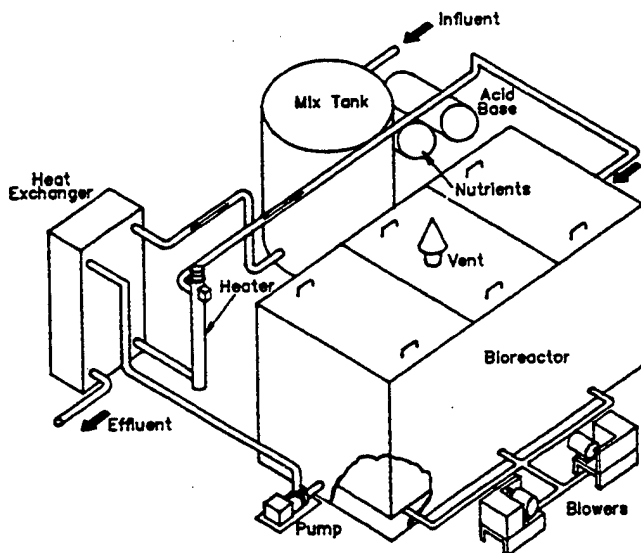
The EPA SITE Program demonstration of this

technology took place from July 24 to September 1, 1989, at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota.

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BioTrol Aqueous Treatment System (BATS)



Biological Arsenic Remediation Arsenic in Wastewaters

Technology Description

This bacterial treatment system provides alternative technology for arsenic removal from contaminated solution. The process uses anaerobic sulfate reducing bacteria (SRB) to produce sulfides which, in turn, precipitate arsenic from solution. The precipitate is removed from solution using conventional solid/liquid separation techniques. One advantage of this system over commonly used ferric arsenic precipitation circuit is the significant reduction in sludge volumes generated.

In this process, bacteria are used in three circuits:

- A two-stage reactor. Stage 1 is a bioreactor for biogenic sulfide production by SRB. The hydrogen sulfide gas and aqueous sulfides (i.e., H_2S , HS^- , S^{2-} , and FeS) produced in the bioreactor are transported to stage 2 where they precipitate arsenic and produce a minimum volume of sludge. This system is applicable to in-line treatment of an industrial process stream.
- Direct arsenic precipitation using arsenic-tolerant SRB. The bacteria grow suspended in the contaminated solution without a solid growth surface for attachment. This system is applicable to passive stabilization of a pond.
- A column system. SRB are grown on a solid growth surface such as carbon or sand. Contaminated solution is pumped up-flow through the reactor. Arsenic-sulfide precipitate accumulates in the column matrix. When the column is saturated, the

arsenic is stripped and biologically regenerated. This system is applicable to semi-passive remediation of a pond or treatment of an industrial process stream.

Technology Performance

Treating industrial wastewater in the column system circuit reduced arsenic contamination from 13 to less than 0.5 milligrams per liter (mg/L). A field demonstration was scheduled to begin late in the summer of 1993.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Information on the site of the planned demonstration was not provided for this publication.

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Biological Cyanide Detoxification Decommissioning of Precious Metals Heap Leaching Facilities

Technology Description

This bacterial treatment system provides alternative rinsing technology for decommissioning precious metals heap leach facilities. This alternative oxidizes cyanide using existing equipment by activating natural populations of cyanide-oxidizing bacteria indigenous to the site and/or introducing additional populations of natural bacteria with known cyanide-degrading capabilities.

Generally, when a spent heap is decommissioned, process solution is recycled through the system until the cyanide concentration in the rinse solution meets an acceptable level. This procedure involves evaporation of as much water as possible by spraying a fine mist on top of the heaps; the solution volume is maintained with fresh-water makeup. The last portion of cyanide remaining in the rinse solution is generally destroyed using a chemical oxidant such as hydrogen peroxide.

The biological remediation technique involves using on-site carbon columns as bioreactors to destroy a portion of the cyanide in the rinse solution as it is circulated through the system. The goals are to speed up the closure process and to eliminate the need for chemical treatment as a polishing step. Ideally, bacterially-enhanced rinsing will completely and permanently destroy the cyanide in the rinse solutions and the spent heaps.

Technology Performance

Full-scale proof-of-concept field testing was successfully conducted at the U.S. Bureau of Mines' Green Springs operation near Ely, NV, from June to October 1992. The carbon adsorption columns in the gold recovery plant were used as the bioreactor. Bacteria consistently oxidized 2 ppm CN in a process solution containing about 20 ppm WAD CN at flow rates up to 300 gpm in 12-14 minutes. A nutrient level of greater than 40 ppm phosphate, added as phosphoric acid, was used. The biologically-treated water was used to rinse the heaps. Results from the field testing showed that carbon tanks could be used as bioreactors; bacteria destroyed cyanide with a very short retention time; USMX continued to recover gold from the activated carbon; bacteria growth was maintained during carbon transfer from tank to tank; and bacteria in the system re-inoculated the new carbon.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Full-scale proof-of-concept field testing was successfully conducted at the U.S. Bureau of Mines' Green Springs operation near Ely, NV.

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Biological Reduction of Selenium Selenium in Process and Wastewaters

Technology Description

This technology uses bacteria to remove selenium from process solutions and wastewaters to levels that meet stringent selenium discharge requirements. It involves biostimulation of indigenous selenium-reducing bacteria and/or introduction of additional bacteria with known selenium-reducing abilities.

The technique utilizes simple bioreactors containing natural bacteria immobilized on solid surfaces. The technology is designed to employ on-site equipment, such as carbon tanks or sand filters, as bioreactors in order to reduce or eliminate capital equipment expense. Activated carbon or sand serves as growth surfaces for the bacteria. Commercial fertilizers and/or sugar-containing agricultural wastes provide bacterial nutrient supplements. Selenium is precipitated and removed from the contaminated water as it is pumped through the system. Elemental selenium, formed in the bioreactors, is removed by flushing and/or using a solid/liquid separation step, such as tangential (cross-flow) filtration.

Technology Performance

Natural bacteria, cultured at the Salt Lake Research Center, have successfully reduced selenium in actual process solutions from four precious metals operations and two uranium mines. The bacteria reduce both selenate and selenite to elemental selenium.

Selenium often is the primary contaminant remaining after cyanide destruction in solutions

from precious metals operations. Because cyanide eliminates most of the natural bacteria in these solutions, they are relatively simple to treat by bioaugmentation after cyanide destruction. Bacteria reduced the selenium concentration in one feed containing 30 ppm to 1.2 ppm in 144 hours. In a second solution, selenium was reduced from 4.2 to 1.6 ppm in 48 hours.

Uranium wastewaters contain numerous selenium reducing and non-selenium reducing bacteria and may be treatable using a combination of biostimulation and bioaugmentation, coupled with more stringent operating conditions. Selenium in two sterilized uranium wastewaters was reduced from 0.58 to 0.03 ppm in 48 hours and from 1.6 to 0.02 ppm in 24 hours.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Testing of this process has been done at the U.S. Bureau of Mines' Salt Lake Research Center. Proof-of-concept field testing at a uranium operation was scheduled for Summer, 1993.

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Biological Treatment

Nitrates, CCl_4 , and CHCl_3 in Ground Water (*In Situ* Treatment)

Treatment Description

This biological treatment system simultaneously removes nitrates and organics from contaminated ground water *in situ*. The technology relies on wells within the contaminated region to introduce and distribute nutrients to achieve favorable conditions for microbial metabolism of the contaminants. If indigenous bacteria do not possess the ability to destroy target compounds, other strains of aquifer microbes can also be introduced to the subsurface.

At DOE's Hanford Site, the technology will be demonstrated by remediating a portion of the aquifer which is contaminated with nitrates, CCl_4 , and CHCl_3 . The treatment process will use facultative anaerobic microorganisms isolated from the Hanford Site that have been shown to degrade both nitrates and CCl_4 .

Technology Performance

Carbon tetrachloride and nitrate destruction by indigenous Hanford microorganisms has been demonstrated with simulated ground water in bench- and pilot-scale reactors. For example, a pilot-scale agitated slurry reactor processing a simulated ground water feed containing 400-ppm and 200-ppb CCl_4 and acetate as the primary carbon source, demonstrated greater than 99 percent and 93 percent destruction of nitrate and CCl_4 , respectively. Work is proceeding to measure hydrodynamic and pertinent chemical properties of the proposed *in situ* bioremediation test site, and to rigorously

study the kinetics of contaminant destruction and growth of the microorganisms. This information is being incorporated into 1- and 3-dimensional simulations of *in situ* bioremediation to help design proper remediation conditions.

Preliminary cost estimates indicate that the technology should cost significantly less than *ex situ* bioremediation, and slightly less than pump-and-treat using air stripping and granular activated carbon (GAC) adsorption. However, the cost estimates are based on soil conditions that favor pump-and-treat (i.e., very permeable soils with very low retardation coefficients). *In situ* bioremediation has the advantage of providing ultimate destruction of the contaminant, requires one-half the time for remediation, and should be much more cost effective in soils that more strongly adsorb volatile organic compounds (VOCs). In addition, *in situ* biodegradation does not require the transportation of spent activated carbon to an off-site disposal or regeneration facility.

Remediation Costs

Carbon tetrachloride removal costs have been estimated to be between \$30 and \$60/1,000 gal of aquifer pore water. These costs are based on a 1 ppm CCl_4 plume in permeable soils with low retardation coefficients.

General Site Information

The Hanford Site, located in southeastern Washington State, is an area of approximately 600 square miles that was selected in 1943 for producing nuclear materials in support of the United States' effort in World War II. Hanford's operations over the last 40+ years have been dedicated to nuclear materials, electrical generation, diverse types of research, and waste management. Some of these operations have produced aqueous and organic wastes that were discharged to the soil column. In the 200 West area of the Hanford Site, plutonium recovery processes discharged CCl_4 -bearing solutions to three liquid waste disposal facilities: a trench, tile field, and crib. A minimum of 637 tons of CCl_4 was disposed to the subsurface, primarily between 1955 and 1973, along with co-contaminants such as tributyl phosphate, lard oil, cadmium, nitrates, hydroxides, fluorides, sulfates, chloroform, and various radionuclides, including plutonium. Near the disposal site, CCl_4 vapors have been encountered in the vadose zone during well-drilling operations, and ground water contamination from CCl_4 covers 5 km^2 . Concentrations up to 1,000 times the EPA drinking water standard of 5 ppb have been measured in the ground water. In addition, nitrate concentrations up to 10 times the EPA drinking water standard of 44 ppm have been measured in the same area of the Site.

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Bioremediation

Bioremediation of Aromatic Hydrocarbons Unleaded Gasoline in Soil and Ground Water

Technology Description

Target contaminants for this treatment are benzene, toluene, ethylbenzene, and xylenes (BTEX) in concentrations ranging from 1 ppb to 4 ppm. Site soil is placed in bioreactors and contaminated ground water is pumped through the bioreactors. Native microorganisms degrade the BTEX.

Technology Performance

A pilot-scale demonstration was conducted at Naval Weapons Station Seal Beach in California, at the site of an unleaded gasoline spill. Three 80-litre bioreactors were used and operated at a capacity of 72 L/day or less. The treatment was evaluated using data from gas chromatography on the influent, effluent, and several sampling points during the process. The demonstration resulted in effluent water being cleaned to drinking water standards for BTEX.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

A pilot-scale demonstration was conducted at Naval Weapons Station Seal Beach in California, at the site of an unleaded gasoline spill.

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Bioremediation

Bioremediation/Vacuum Extraction Petroleum Fuels in Soil

Technology Description

This process begins with removing soil contaminated with fuels and stockpiling it for treatment. This technology can be applied to soils contaminated with diesel, JP-5, or other fuels that have leaked from underground storage tanks.

In order to decontaminate the stockpiled soil, it is processed through a screen to eliminate rocks greater than four inches in diameter. The screened soil is transported to a site that is protected by a 40-milliliter liner with eight inches of sand base. A three-foot layer of contaminated soil is spread along the base of the prepared pile and then a series of vacuum extraction pipes are trenched in the soil and connected to a Vacuum Extraction System (VES) blower. The VES blower provides movement of oxygen through the pile. The remaining soil is piled into a trapezoid shape about 15 feet high, 200 feet long, and 60 feet wide. Fertilizer is added, and an irrigation system is installed. Computer-controlled sensors are placed within the pile to monitor temperature, pressure, and soil moisture.

Technology Performance

The field pilot test conducted in Bridgeport, California, showed two results:

- After approximately two months of operation, the average concentration of total petroleum hydrocarbons (TPH) was 120 ppm; and

- The Navy declared the tested sites "clean" in a report prepared for the California Regional Water Quality Control Board.

Remediation Costs

Remediation costs are estimated at approximately \$80/ton of soil at the Bridgeport, California, pilot project.

General Site Information

A field pilot test was conducted at Bridgeport, California, in fiscal year 1989.

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Bioslurry Reactor

PAHs in Soils, Sediments, and Sludge

Technology Description

This slurry-phase bioremediation (bioslurry) technology is designed to biodegrade creosote-contaminated materials by employing aerobic bacteria that use the contaminants as their carbon source. The technology uses batch and continuous flow bioreactors to process polycyclic aromatic hydrocarbon (PAH)-contaminated soils, sediments, and sludges. The bioreactors are supplemented with oxygen, nutrients, and a specific inocula of enriched indigenous microorganisms to enhance the degradation process.

Because site-specific environments influence biological treatment, all chemical, physical, and microbial factors are designed into the treatment process. The ultimate goal is to convert organic wastes into biomass, relatively harmless by-products of microbial metabolism, such as carbon dioxide, methane, and inorganic salts. Biological reaction rates are accelerated in a slurry system because of the increased contact efficiency between contaminants and microorganisms.

Slurry-phase biological treatments can be applied in the treatment of highly contaminated creosote wastes. It can also be used to treat other concentrated contaminants that can be aerobically biodegraded, such as petroleum wastes. The bioslurry reactor system must be engineered to maintain parameters such as pH, temperature, and dissolved oxygen, with ranges conducive to the desired microbial activity.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in spring 1991. From May through September, 1991, EPA conducted a SITE demonstration using six bioslurry reactors at EPA's Test and Evaluation Facility in Cincinnati, Ohio.

ECOVA Corporation conducted bench- and pilot-scale process development studies using a slurry phase biotreatment designed to evaluate bioremediation of PAHs in creosote contaminated soil collected from the Burlington Northern Superfund site in Brainerd, Minnesota. Bench-scale studies were performed prior to pilot-scale evaluations in order to collect data to determine the optimal treatment protocols. EIMCO Biolift slurry reactors were used for the pilot-scale processing. Data obtained from the optimized pilot-scale program will be used to establish treatment standards for K001 wastes as part of the EPA's Best Demonstrated Available Technology (BDAT) program.

Slurry-phase biological treatment significantly improved biodegradation rates of carcinogenic 4- to 6-ring PAHs. The pilot-scale bioreactor reduced 82 ± 15 percent of the total soil-bound PAHs in the first week. After 14 days, total PAHs had been biodegraded by 96 ± 2 percent. An overall reduction of 97 ± 2 percent was seen over a 12-week treatment period, indicating that almost all biodegradation occurred within the first two weeks of treatment. Carcinogenic PAHs were biodegraded by 93 ± 3.2 percent to 501 ± 103 mg/kg from levels of $5,081 \pm 1,530$ mg/kg.

Remediation Costs

Cost information was not provided for this publication.

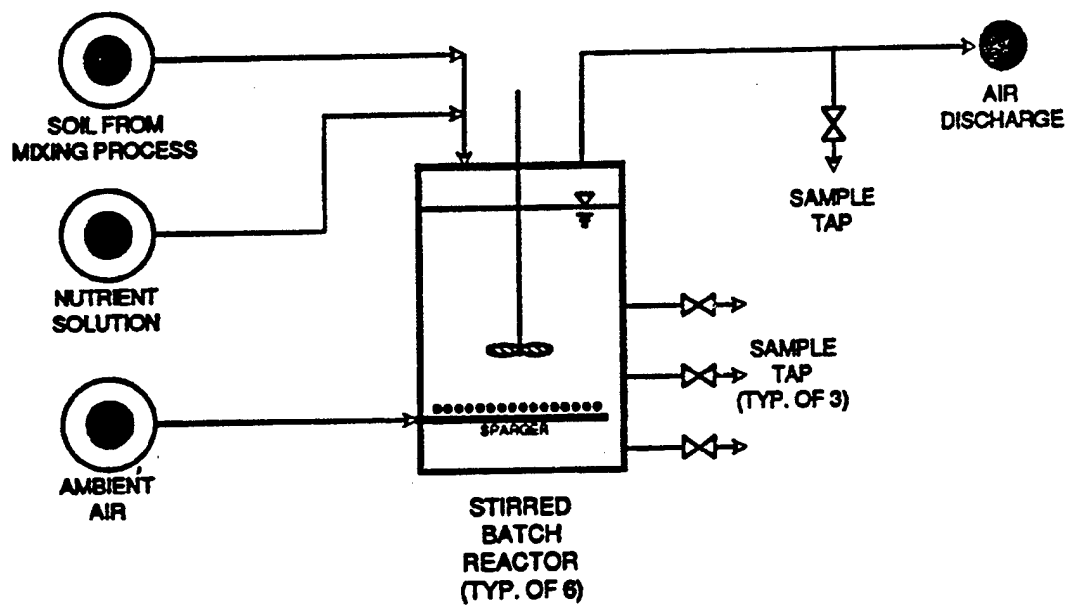
General Site Information

EPA conducted a SITE demonstration using six bioslurry reactors at EPA's Test and Evaluation Facility in Cincinnati, Ohio.

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Bioslurry Reactor



Bioventing

PAHs in Soil (*In Situ* Treatment)

Technology Description

This technology injects atmospheric air into contaminated soil. This provides a continuous oxygen source, enhancing the growth of microorganisms naturally present in the soil. Additives also may be required to stimulate microbial growth.

This technology uses an air pump attached to one of a series of air injection probes. The air pump operates at extremely low pressures, allowing inflow of oxygen without significant volatilization of contaminants in the soil. The treatment capacity depends on the numbers of injection probes, the size of the air pump, and site characteristics such as soil porosity.

This system is typically used to treat soil contaminated by industrial processes and can treat any contamination subject to aerobic microbial degradation. Different contaminants and combinations of contaminants may result in varied degrees of success.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1991, and a demonstration was initiated in November 1992 at the Reilly Tar site in St. Louis Park, Minnesota. It will be completed in November 1995.

Remediation Costs

Cost information is not yet available.

General Site Information

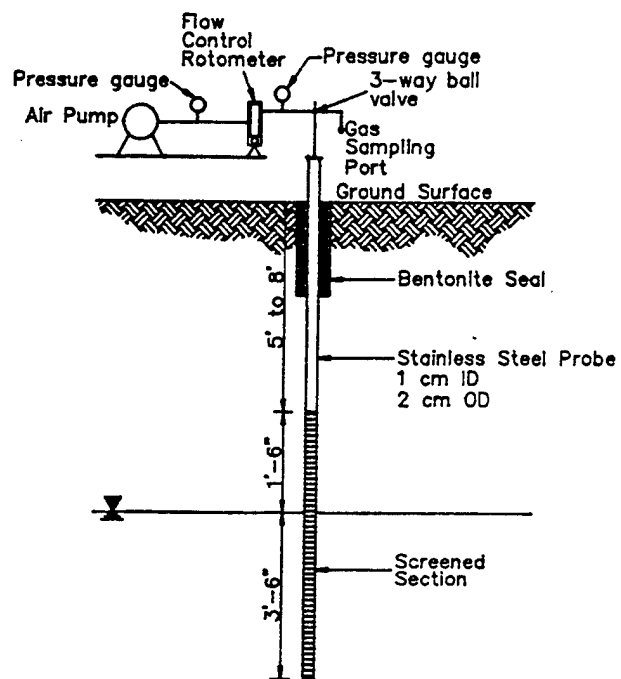
A demonstration was conducted late at the Reilly Tar site in St. Louis Park, Minnesota.

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EPA Bioventing System



Bioventing

JP-5 Jet Fuel in Soil and Ground Water (*In Situ* Treatment)

Technology Description

This technology is used to treat soil and ground water contaminated with petroleum hydrocarbons. The treatment system consists of dewatering wells equipped with low vacuums to draw air through the contaminated zone and disperse the more volatile jet fuel components. Aeration of the vadose zone also promotes aerobic biodegradation of fuel hydrocarbons.

Water, soil vapor, and free fuel product are extracted from dewatering wells simultaneously. Any water/fuel mixture is separated in an oil/water separator, since the water requires treatment in a permitted plant. Vapor emissions should be low, below regulatory levels. Biodegradation occurs within the vadose zone.

Two limitations can affect use of this technology:

- Soil temperature should be kept above 10°C for optimal use of this technology;
- Heavy soils can impede, but do not inhibit, oxygen gas diffusion through subsoil.

Technology Performance

A pilot test of this technology was conducted in mid-1992 at Fallon Air Force Base in Nevada. In preparation for the test, *in situ* respirometry was performed at the site to test for potential effectiveness of the bioventing technology, and

the respirometric data was compared to sites where bioventing has been successful.

Most of the contamination at the site is in an impure sand horizon at a 7-to-10-foot depth, sandwiched between two clay lake bed strata. It is unknown how this scenario will affect achievement of cleanup goals.

Bioventing at the site is expected to continue for about 18 months. However, total time required for cleanup is unknown, since data on diesel and other low volatility fuels is lacking at this time.

Remediation Costs

Cost of this treatment, during the pilot test, is estimated at \$65/cubic yard of contaminated soil. This should be significantly higher than the cost for use of the technology in full-scale remedial operations.

General Site Information

The test is being conducted at a JP-5 leakage site at New Fuel Farm at Fallon AFB in Nevada. New Fuel Farm is being actively used by the Navy for aircraft refueling and will continue to be used throughout the test. In the treatment plot, which covers just over 1 acre, total TPH concentration is between 2,000 and 7,000 mg/kg (using California LUFT method). Benzene was detected in one soil sample at 0.1 mg/kg., and arsenic is naturally high in ground water.

The total contaminated plume at this site covers six acres.

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Bioremediation

Bioventing in the Vadose Zone Petroleum Hydrocarbons in Unsaturated Soil (*In Situ* Treatment)

Technology Description

Bioventing is an *in situ* bioremediation technology that can be applied to the cleanup of unsaturated soils contaminated with petroleum hydrocarbons. The Air Force has identified more than 4,400 sites requiring investigation and possible remediation through the Installation Restoration Program. At least half of these sites are contaminated with petroleum hydrocarbons and may be amenable to bioventing.

Soil venting has been proven effective for the physical removal of volatile hydrocarbons from unsaturated soils. This technology can also provide oxygen for the biological degradation of the fuel contaminants. Common strains of soil bacteria have been proven capable of biodegrading fuel hydrocarbon components.

Through the optimization of the venting air flow rates and possible nutrient/moisture addition, the proportion of hydrocarbon removal by *in situ* biodegradation can be optimized. This approach may eliminate the need for off-gas treatment, thereby reducing overall site remediation costs.

This technology has a number of benefits:

- It does not require excavation of the contaminated material — this technology will treat soil in place;
- By optimizing the amount of hydrocarbon removal by *in situ* biodegradation and thereby minimizing the amount of hydrocarbons volatilized and removed in the off-gas, the requirement for off-gas

treatment, such as catalytic incineration, may be eliminated. This can reduce the overall treatment cost by 50 percent;

- The less volatile residual fuel organics which may not be treated by soil venting alone can be treated with bioventing.

Technology Performance

The pilot-scale field test at Tyndall AFB in Florida was successful:

- Under optimum conditions, approximately 80 percent hydrocarbon removal could be attributed to the mechanism of *in situ* biodegradation;
- Biodegradation removal rates ranged from 2 to 20 milligrams per kilogram (mg/kg) of soil per day; and
- Although additional nutrients and moisture did not affect biodegradation rates at this specific site, *in situ* soil temperatures did significantly affect these rates.

Remediation Costs

Remediation costs are estimated at approximately \$12 to \$15/cubic yard (yd³) of contaminated soil. This estimate assumes no off-gas treatment will be required.

General Site Information

A pilot-scale field test was conducted at POL Area B at Tyndall Air Force Base, Florida, between July, 1989 and August, 1990. This field study involved four small treatment plots, approximately twenty feet by six feet by five feet deep. The site was previously used as a JP-4 jet fuel storage area.

Additional information on an Air Force initiative to test bioventing at Air Force sites contaminated with petroleum hydrocarbons is available in Appendix B.

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Bioventing in Sub-Arctic Environments Petroleum Hydrocarbons in Unsaturated Soil (*In Situ* Treatment)

Technology Description

Bioventing is an *in situ* bioremediation technology that can be applied to the cleanup of unsaturated soils contaminated with petroleum hydrocarbons. The Air Force has identified more than 4,400 sites requiring investigation and possible remediation through the Installation Restoration Program. At least half of these sites are contaminated with petroleum hydrocarbons and may be amenable to bioventing.

Bioventing enhances the aerobic biodegradation of hydrocarbon contaminants by moving air through the contaminated soil. Benefits of this technology include minimizing the amount of hydrocarbons volatilized and eliminating the need for off-gas treatment. In addition, bioventing is cost-effective and non-invasive, allowing the technique to be employed in many areas.

Technology Performance

A research project was initiated in 1991 at Eielson Air Force Base, Alaska, to study the effectiveness of bioventing and several soil warming methods to remediate jet fuel from unsaturated soil. This project is a collaborative effort between the U.S. Air Force and the U.S. EPA Risk Reduction Engineering Laboratory (RREL). The objective of the study is to demonstrate in the field that biodegradation rates during bioventing can be increased, on a time-averaged basis, in sub-arctic environments by warming the soil. The soil warming methods included in the study were selected for

their relatively low cost of operation. The techniques include:

- Passive warming: enhanced solar warming in late spring, summer, and early fall using clear plastic covering and passive heat retention the remainder of the year by applying insulation on the surface of the plot;
- Active warming: applying heated water (35°C to 40°C at an overall rate of about one gal/min) from parallel soaker hoses below the surface of the plot which is covered in insulation throughout the year; and
- Buried heat tape: burying heat tape in parallel lines running the length of the plot. The tape heats at 6 W/ft giving a total heat load onto the plot of roughly 2,600 W.

The first two years of the study have been successful:

- All three soil warming methods maintained soil temperatures above ambient temperatures throughout the winter. The active warming method generated the highest *in situ* soil temperatures.
- The trend of higher biodegradation rates at higher temperatures was clear. Biodegradation rates at the bioventing site remained relatively high during the winter months in the active warming test plot and were consistently higher than those

observed in the passive warming and control test plots.

- Studies suggest the active warming system operated in conjunction with bioventing has been a useful method for remediating fuel-contaminated areas in cold climates.

The only successful year-round bioremediation effort in Alaska, this project has provided preliminary indications that *in situ* soil warming by active means does increase the rate of biodegradation and could extend the season during which bioventing would be functional in a cold weather environment.

Remediation Costs

An economic comparison of the various soil warming techniques will be prepared following the conclusion of the study in September 1994.

General Site Information

Eielson AFB is located near Fairbanks, Alaska. At the study site, unsaturated soil is contaminated with JP-4 jet fuel resulting from one or more releases associated with the fuel distribution network. Soils at the site consist of inter-bedded layers of loose sand and gravel with silt concentration increasing to a depth of 6 to 7 ft. Depth to ground water is approximately 7 ft. Experimental plots are 50 ft square and spaced about 30 ft apart. Climate is characteristically sub-arctic with low annual precipitation and an average annual temperature near 0°C. There is no permafrost.

Additional information on an Air Force initiative to test bioventing at Air Force sites contaminated with petroleum hydrocarbons is available in Appendix B.

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Bioremediation

Enzyme Catalyzed, Accelerated Biodegradation Diesel Fuel, Heating Fuel Oil, Hydraulic Oils and Glycol in Soil

Technology Description

This treatment, called the Bio-Treat System®, involves *ex situ* bioremediation of contaminated soil in a biocell. The treatment site is located on a concrete pad with a surrounding drainage ditch allowing any runoff to flow into an oil/water separator. Using a 30-day treatment process, hydrocarbon degrading bacteria are applied twice, once on Day 1 and again on Day 8. Enzyme and nutrient are applied twice, once on Day 1 and again on Day 6. Polyphasic suspension agent (PSA) is applied five times on Days 1, 4, 8, 18, and 21. The products are applied with a garden hose, pump, and 300-gallon drum. The soil is tilled with a garden tractor after each product application and once each week.

Monitoring consists of initial waste screening using (EPA) tests 8015, 8020, 8240, and 8270. Post-treatment tests used depend on contaminants found in the waste during initial screening.

Rainfall can affect use of this process since it interferes with aerobic biodegradation, but covering the biocell can eliminate this limitation.

Technology Performance

The U.S. Marine Corps Base at Camp Pendleton, California, conducted a pilot study of this technology in 1991 on contaminated soil from oil/water separator sumps at Camp

Pendleton. Target contaminants were diesel, benzene, ethylbenzene, toluene, and xylenes, with an average TPH of 29,000 ppm. After 29 days of treatment, the process had reduced total petroleum hydrocarbons (TPH) to an average of 88 ppm, well below the 100 ppm goal of the study.

Capacity of the system used in the study was 50 yd³/month. (A larger system proposed could handle 10,000 yd³/month under an enclosed, storm-proof building.) Total time required for operation and maintenance was 40 days.

The process produced no residual waste. No future maintenance of the system was required. The remediated soils were hauled to a beneficial use area on base. No future monitoring was required by the local health department or water quality authority.

Remediation Costs

Costs, including design, for the pilot study are estimated at \$351/yd³ of contaminated soil.

General Site Information

A pilot study was conducted in 1991 at the U.S. Marine Corps Base at Camp Pendleton, California.

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Fungal Treatment Technology

Chlorinated Organics and PAHs in Soil (*In Situ* Treatment)

Technology Description

This biological treatment system uses white rot fungi to treat soils *in situ*. These lignin-degrading fungi bioremediate chemicals found in the wood preserving industry, including chlorinated organics and PAHs.

Organics materials inoculated with the fungi are mechanically mixed into the contaminated soil. Using enzymes normally produced for wood degradation, the fungi also break down contaminants in the soil.

Because this technology uses a living organism, the greatest degree of success occurs with optimal growing conditions. Additives that enhance growth conditions may be required for successful treatment. Moisture control is necessary, and temperature also may be controlled. Nutrients, such as peat, may be added to soils deficient in organic carbon.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1991. A treatability study was conducted in 1991 at the Brookhaven Wood Preserving site in Brookhaven, Massachusetts. Study results showed 89 percent removal of PCP and 70 percent removal of total PAHs, during a 2-month period, by one lignin-degrading fungus.

A full-scale demonstration using this fungus was conducted to obtain economic data. The full-scale project involved a ¼-acre plot of

contaminated soil and two, smaller control plots. The plots were inoculated with *Phanaerochaetes sordida*, a species of white rot fungus. No wood chips or other bulking agents were added to the prepared soil.

Field activities included tilling and watering all plots. No nutrients were added. The treatment was optimized for PCP degradation, but it was expected that PAHs also would be degraded.

Air emissions data showed no significant hazards to field technicians due to soil tilling activities. Contaminated soil, underlying sand, and leachate were sampled for contaminants. The project was completed late in 1992, and initial reports were expected to be available in 1993.

Full-scale performance of the fungal treatment technology did not meet expectations. Further field applications and engineering research are required.

Remediation Costs

Cost information was not calculated for this demonstration.

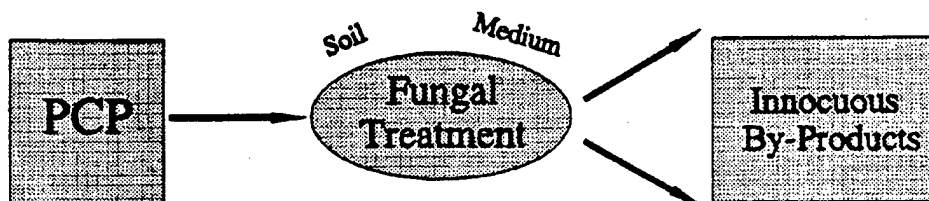
General Site Information

A treatability study and full-scale demonstration using this fungal treatment was conducted at the Brookhaven Wood Preserving site in Brookhaven, Massachusetts.

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Fungal Treatment Process



Immobilized Cell Bioreactor (ICB) Biotreatment System

Polycyclic Aromatic Hydrocarbons (PAHs), Phenols, Gasoline,
Chlorinated Solvents, Diesel Fuel, and Chlorobenzene in Ground Water

Technology Description

The immobilized cell bioreactor (ICB) biotreatment system is an aerobic, anaerobic, or combined aerobic/anaerobic fixed-film bioreactor system designed to remove organic contaminants (including nitrogen-containing compounds and chlorinated solvents) from process wastewater, contaminated ground water, and other aqueous streams. The system offers improved treatment efficiency through the use of (1) a unique, proprietary reactor medium that maximizes the biological activity present in the reactor and (2) a proprietary reactor design that maximizes contact between the biofilm and the contaminants. These features result in quick, complete degradation of target contaminants to carbon dioxide, water, and biomass. Additional advantages include (1) high treatment capacity, (2) compact system design, and (3) reduced operations and maintenance costs resulting from simplified operation and low sludge production. Basic system components include the bioreactor(s), media, mixing tanks and pumps, feed pump, recirculation pump, and a blower to provide air to the aerobic bioreactor.

Depending on the specifics of the influent streams, some standard pretreatments, such as pH adjustment or oil and water separation, may be required. Effluent clarification is not required for the system to operate, but may be required to meet the specific discharge requirements.

The ICB biotreatment system has been successfully applied to industrial wastewater and

ground water containing a wide range of organic contaminants, including PAHs, phenols, gasoline, chlorinated solvents, diesel fuel, and chlorobenzene. Industrial streams amenable to treatment include wastewaters generated from chemical manufacturing, petroleum refining, wood treating, tar and pitch manufacturing, food processing, and textile fabricating. The developer has reported obtaining organic chemical removal efficiencies of greater than 99 percent. The ICB biotreatment system, because of its proprietary medium, is also very effective in remediating contaminated ground water streams containing trace organic contaminants. The ICB biotreatment system can be provided as a complete customized facility for specialized treatment needs or as a packaged modular unit. The technology can also be used to retrofit existing bioreactors by adding the necessary internal equipment and proprietary media. The table below summarizes recent applications.

Table 1. Current Applications

<u>Applications</u>	<u>Contaminants</u>	<u>Scale</u>
Pipeline Terminal Wastewater	COD, Benzene, MTBE, Xylenes	Commercial
Specialty Chemical Wastewater	Cresols, MTBE, PAH, Phenolics	Commercial
Ground Water	Chlorobenzene, TCE	Pilot
Tar Plant Wastewater	Phenol, Cyanide, Ammonia	Commercial
Wood Treating Wastewater	Phenolics, Creosote	Commercial

Technology Performance

A TCE-contaminated site in St. Joseph, Michigan, has been chosen for the demonstration of the dual ICB anaerobic/aerobic system for bioremediation of chlorinated solvents, and a demonstration plan is being developed. This system is designed with a completely enclosed headspace, eliminating the possibility of air stripping of volatile organics or intermediates. The process was tested both in the laboratory and on the pilot scale and demonstrated efficient removal of high levels of TCE (>100 ppm) to the low ppb levels in less than a 24-hour HRT.

Remediation Costs

Cost information was not provided for this publication.

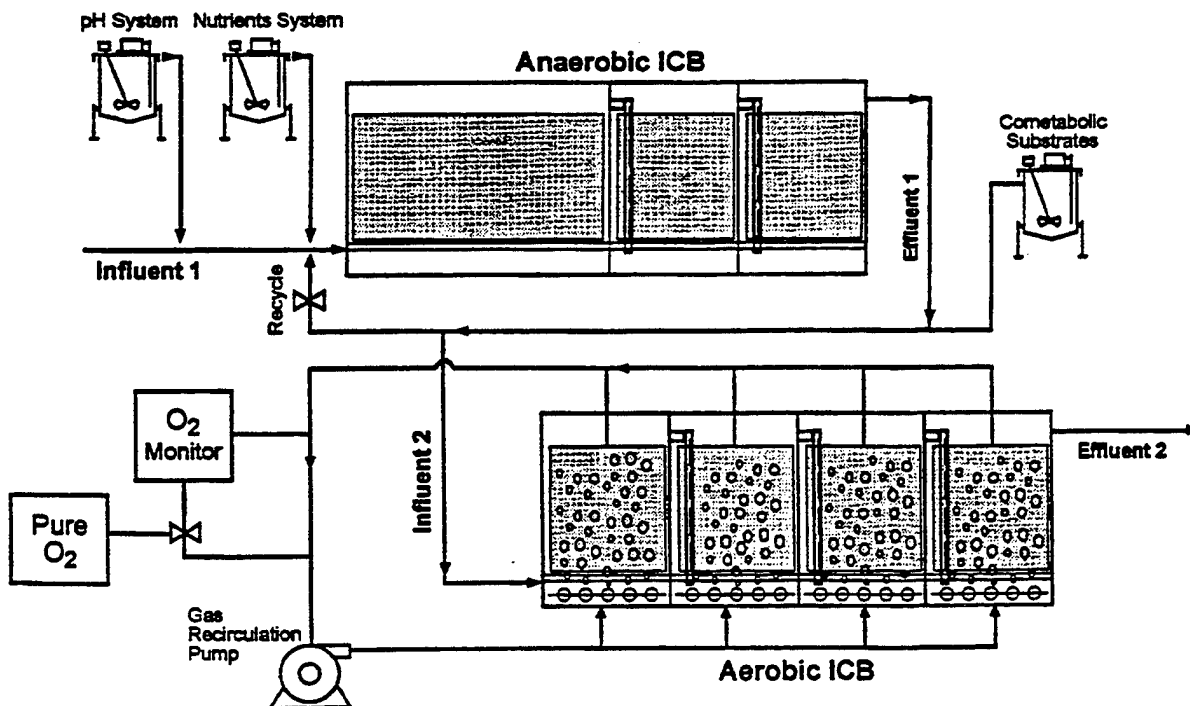
General Site Information

A TCE-contaminated site in St. Joseph, Michigan, has been chosen for the demonstration of this technology.

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Bioremediation

***In Situ* and Above-Ground Biological Treatment of Trichloroethylene Trichloroethylene (TCE) in Ground Water**

Technology Description

This treatment technology uses specific bacterial cultures to degrade chlorinated organic compounds. A unique bioreactor has been designed to use methane-degrading bacteria to co-metabolize TCE. Another biological treatment system use an altered microorganism in an upflow packed bed bioreactor to determine the efficiency of TCE degradation without the presence of a co-metabolic inducer. These reactions can take place in a bioreactor or *in situ*.

Technology Performance

A preliminary pilot-scale test of a co-metabolic treatment was conducted at Tinker Air Force Base, Oklahoma in 1989 using the methane-degrading bacteria. Approximately 80 percent destruction of TCE was achieved.

A joint effort is currently underway by the U.S. Air Force and the DOE Oak Ridge National Laboratory (ORNL), Tennessee, to perform a co-metabolic techniques demonstration, comparing two different biological systems in the field to determine their ability to degrade chlorinated organic compounds. A reactor inoculated with a methanotrophic culture will be operated alongside a bioreactor seeded with a *Pseudomonas* culture capable of degrading TCE in the presence of select aromatic compounds. The objectives of the study include determining which culture is most effective at biodegrading a waste mixture and optimizing this bioreactor

process. These two biological systems use the co-metabolic process for TCE degradation.

A technology demonstration using the altered bacteria in an above-ground bioreactor will be followed by an *in situ* treatment test in a contaminated aquifer. This strain of bacteria degrades TCE without the need of a co-metabolic interaction with a toxic inducer.

Remediation Costs

Cost information will not be available until completion of these technology demonstrations.

General Site Information

The co-metabolic techniques demonstration using unique biological systems is underway at the K-25 site (Oak Ridge Gaseous Diffusion Plant) at ORNL. The demonstration using altered bacteria is being conducted at Hanscom Air Force Base, Massachusetts.

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***In Situ* Anaerobic Biodegradation Jet Fuel in Ground Water**

Technology Description

This technology enhances the anaerobic biodegradation of jet fuel components through the addition of nitrate. Fuel has been shown to degrade rapidly under aerobic conditions, but success often is limited by the inability to provide sufficient oxygen to the contaminated zones due to the low water solubility of oxygen. Nitrate also can serve as an electron acceptor and is more soluble in water than oxygen. The addition of nitrate to an aquifer results in the anaerobic biodegradation of toluene, ethylbenzene, and xylenes (TEX). The benzene component of fuel has been found to be recalcitrant under strictly anaerobic conditions. A mixed oxygen/nitrate system would prove advantageous in that the addition of nitrate would supplement the demand for oxygen rather than replace it, allowing for benzene to be biodegraded under microaerophilic conditions.

Technology Performance

Two previous *in situ* bioremediation field tests which used hydrogen peroxide to enhance the aerobic degradation of jet fuel showed poor oxygen transfer and utilization and aquifer plugging due to geochemical reactions resulting in poor overall performance of this technology. A joint effort is underway by the U.S. Air Force and EPA's Robert S. Kerr Environmental research Laboratory (RSKERL) to perform an enhanced anaerobic field demonstration at a petroleum, oils, and lubricant (POL) contamination site at Eglin AFB in Florida. Field work for this effort began in March 1993 with site characterization activities and sample

collection for laboratory treatability tests. Construction of the treatment system will begin in January 1994, and operation will continue for about nine months.

Remediation Costs

One cost estimate is in the range of \$160 to \$230/gal of residual fuel removed from the aquifer. This estimate does not include an estimate for the extensive site characterization required to determine soil/chemical compatibility.

General Site Information

The nitrate enhancement demonstration will be conducted at Eglin AFB in Florida. The site was previously used for one of the hydrogen peroxide studies. It is characterized by permeable, sandy soil and a very shallow aquifer. Specific site details are available from the Air Force in the technical report documenting the previous hydrogen peroxide study (ESL-TR-88-87).

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Bioremediation

***In Situ* Biodegradation** **Fuels, Fuel Oils and Non-halogenated Solvents in Soil and Ground Water**

Technology Description

This *in situ* biodegradation process treats soil or ground water contaminated with hydrocarbons such as fuels, fuel oils, and non-halogenated solvents. This technology can be applied to fuel spills, leaky storage tanks, and fire training pits.

Nutrients (especially nitrogen and phosphorus), soil-conditioning chemicals, and an electron acceptor (oxygen source or nitrate) are introduced to the aquifer through irrigation wells, ditches, or soil surface irrigation. Pumping wells remove excess fluids or contaminated ground water. Contaminated water can be treated on the surface or reinjected for treatment in the soil. Monitoring wells must be placed within and surrounding the site.

Technology Performance

Two field tests of this process have been completed using hydrogen peroxide as the electron acceptor. The first test was conducted at Kelly Air Force Base in Texas, the second at Eglin AFB in Florida. Neither site was ideal for this method. At Kelly AFB, the injection wells became clogged from precipitation of calcium phosphate, which reduced their injection capacity by 90 percent. At Eglin AFB, problems with the aquifer plugging due to iron precipitation were encountered in addition to the rapid decomposition of hydrogen peroxide. These field tests showed that the design of hydraulic delivery systems and the compatibility of injection chemicals with soil

minerals is as important to successful treatment as the enhancement of bacteria.

Remediation Costs

Exclusive of site characterization, one estimate of the cost range of this method is from \$160 to \$230/gal of residual fuel removed from the aquifer. Monitoring would be expensive, depending upon the type of contaminant. Site characterization must be done to determine soil/chemical compatibility.

General Site Information

Field tests conducted at Kelly AFB, Texas, and Eglin AFB, Florida, were completed at JP-4 jet fuel contamination sites.

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***In Situ* Biodegradation TCE in Ground Water**

Technology Description

Picatinny Arsenal is the U.S. Geological Survey (USGS) Toxic Waste Hydrology Program's national demonstration site for chlorinated solvents in ground water. Earlier work has looked at many of the processes which can affect the fate and transport of TCE in the system, including volatilization to the unsaturated zone, aerobic biodegradation, anaerobic biodegradation, and sorption/desorption to/from aquifer sediments. Solute transport modeling has also been done to integrate these studies.

The distribution of TCE in the soil gas has been determined by the installation and sampling of 50 vapor probes at the site. A strong disequilibrium has been found to exist between the soil and vapor TCE concentrations. That is, there is much more TCE on the soil than predicted based on the soil gas TCE concentrations. Similarly, more TCE has been found in soil water than predicted based on the soil gas TCE concentrations.

Work on determining the feasibility of using aerobic *in situ* biodegradation of TCE vapors as a remediation strategy at Picatinny Arsenal has begun. This work has been funded by the U.S. Environmental Protection Agency. Laboratory microcosm studies using soil from near the source of the TCE contamination have been conducted and results show that the indigenous methanotrophic bacteria from this site can cometabolically degrade vapor-phase TCE when appropriate amounts of methane, oxygen, and nutrients are amended to soil microcosms.

Technology Performance

Up to 82 percent removal of vapor-phase TCE concentration has been observed after only eight days in these laboratory tests. A pilot-scale facility utilizing this technology is proposed for the field site. It will include either venting the soil in the unsaturated zone or sparging a contaminated well near the source to produce a vapor stream containing TCE. The vapor stream will be amended with appropriate amounts of a degradable hydrocarbon (methane, propane, or natural gas) and oxygen, and then either (1) reinjected into the unsaturated zone to allow *in situ* remediation to take place, or (2) channeled into an above-ground soil bioreactor to allow remediation to take place.

Anaerobic TCE degradation has been documented to occur in the saturated zone at Picatinny Arsenal. The rates of reductive dehalogenation of TCE to cis-1,2-dichloroethylene to vinyl chloride were measured in soil microcosm studies using aquifer sediments from the plume. Anaerobic TCE degradation is an active and viable *in situ* remediation process at the site. Enhancement or stimulation of this process is the subject of proposed study.

Experiments looking at the sorption/desorption of TCE from saturated zone sediments have shown that desorption of TCE from long-term contaminated sediments is kinetically slow. A disequilibrium has been found to exist between the soil and water TCE concentrations in the aquifer. That is, there is much more TCE on

the sediments than would be predicted based on the measured TCE concentrations in ground water. These findings infer that pump-and-treat remediation will not remove the major pool of TCE in the system which is TCE on the sediments.

The use of surfactants to increase removal of TCE from an aquifer also is the subject of proposed study. Laboratory tests will be conducted to determine the effect of introducing a surfactant on the hydraulic properties of the aquifer and the apparent solubility of TCE in the aquifer. A field-scale experiment is proposed to determine the effectiveness of the chosen surfactant on the contaminated aquifer system at Picatinny Arsenal. If successful, this approach will address the need to get the TCE off of the sediment and into the aqueous phase for remediation.

A solute-transport model has been modified to facilitate transport of more than one solute at a time and also include reactions between these different solutes. This state-of-the-art modeling effort will be used to include the appearance and disappearance of breakdown products and to incorporate the determined reaction rates between these products. Also, the measured rates of desorption and volatilization will be input so the model will be able to integrate the effects of all the different processes investigated to come up with a more accurate simulation of the distribution and transport of TCE at the site.

Remediation Costs

No cost information is available at this time.

General Site Information

Contamination of ground water, primarily with TCE, at Picatinny Arsenal, New Jersey, has been caused by improper disposal of wastewater from a metal plating/degreasing operation. Picatinny Arsenal is a federally owned property operated by the U.S. Army. The New Jersey

District of the USGS has had a long history of favorable cooperation with the Army at this site.

The TCE ground water plume (1,000 feet wide by 2,000 feet long by 60 feet thick) at Picatinny Arsenal has been well characterized over the past 10 years by the USGS. The plume is one of the world's best instrumented with TCE distribution being defined both areally and vertically by the installation and sampling of 15 drive-point sites and 75 observation wells. Samples have been analyzed for volatile organic chemicals (VOCs), major cations and anions, trace elements, nutrients, and dissolved organic carbon. The hydrology of the plume area is well known and is included in the area of an existing three-dimensional ground water flow model. The geology of the plume area has been defined by lithologic logs, geophysical logs, and particle size analysis.

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Bioremediation

In Situ Enhanced Bioremediation Jet Fuel in Ground Water

Technology Description

The approach used in this process involves enhanced bioremediation. Initial tests are done to determine if naturally occurring microbes present in the aquifer are capable of degrading the contamination. Then, the rate-limiting nutrients are determined. Ground water is pumped from an uncontaminated source with low concentrations of dissolved iron and amended by adding the necessary nutrient(s). The amended water is pumped into a series of infiltration galleries (french drains) laterally transecting the contamination plume. Approximately 20 feet downgradient from the infiltration galleries, a line of extraction wells pumps contaminated ground water out of the ground and discharges it to a permitted treatment facility. Several observation wells in the area are monitored to evaluate the effectiveness of the system.

Technology Performance

Testing of this process is being conducted at the Defense Fuel Supply Point, Hanahan, South Carolina. Laboratory experiments have shown that microbes capable of degrading the contamination occur naturally in contaminated ground water at the site. Examination of field data showed that microbial degradation of organic contaminants was occurring at the site. The terminal electron accepting processes occurring in most areas of the site were sulfate reduction and methanogenesis. In part of the contaminated ground water, respirative activity was significantly reduced relative to

fermentative activity. Laboratory tests demonstrated that replacement of the pore water with sterile, uncontaminated water amended with nitrate was sufficient to stimulate respirative activity in the aquifer sediment. Field testing of the bioremediation system was scheduled to begin in late summer, 1993.

Remediation Costs

No cost information is available at this time.

General Site Information

The test site is a fuel tank farm at Defense Fuel Supply Point, Hanahan, South Carolina. The contamination is dominantly JP-4 jet fuel, and the target compounds are benzene, toluene, ethylbenzene, and xylene (BTEX). The ground water contamination extends off the facility property and into a nearby neighborhood. The bioremediation system is divided into three major sections. The bioremediation approach at each of the three sections will differ to allow conclusions to be drawn regarding the reactive effectiveness of the approaches.

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Liquids and Solids Biological Treatment (LST) Biodegradable Organics in Soils, Sediments, and Sludge

Technology Description

Liquid and solids biological treatment (LST) is a process that can be used to remediate soils and sludges contaminated with biodegradable organics. The process is similar to activated sludge treatment of municipal and industrial wastewaters, but it occurs at substantially higher suspended solids concentrations (such as greater than 20 percent). An aqueous slurry of the waste material is prepared and environmental conditions (for example, nutrient concentrations, temperature, and pH) are optimized for biodegradation. The slurry is then mixed and aerated for a sufficient time to degrade the target waste constituents.

Several physical process configurations are possible for LST of contaminated soil and sludges, depending on site- and waste-specific conditions. Batch or continuous treatment can be conducted in impoundment-based reactors. This is sometimes the only practical and economically viable option for very large (greater than 10,000 yds.³) projects. Alternatively, tank-based systems may be constructed.

Constituent losses due to volatilization are often a concern during LST operations. The potential for emissions is greatest in batch treatment systems and lowest in continuously stirred tank reactor systems, particularly those with long residence times. Various technologies (such as carbon adsorption and biofiltration) can be used to manage emissions.

Bioremediation by LST may require a sequence of steps involving pre- and post-treatment operations. The only instance in which multiple unit operations are not required is strictly *in situ* applications where treated sludge residues are destined to remain in place.

Overall bioremediation in a hybrid system, consisting of both LST and land treatment systems, can provide an alternative to landfilling treated solids. Combining these two approaches rapidly degrades volatile constituents in a contained system, thereby rendering the material suitable for landfilling.

The developer has constructed a mobile LST pilot system for field demonstrations. The system consists of two reaction vessels, two holding tanks, and associated process equipment. Tank operating volumes are 2,000 gallons. The reactors are aerated using coarse bubble diffusers and mixed using axial flow turbine mixers. The reactors can be operated separately or in combination as batch or continuous systems. Oxygen and pH are continuously monitored and recorded. Additional features include antifoaming and temperature control systems. Pre- and post-treatment equipment is provided separately depending on site-specific circumstances and project requirements.

The technology is suitable for treating sludges, sediments, and soils containing biodegradable organic materials. To date, the process has been used mainly for treating sludges containing petroleum and wood preservative organics such as creosote and PCP. PAHs, PCP, and a broad

range of petroleum hydrocarbons (such as fuels and oils) have been successfully treated with LST in the laboratory and the field.

Technology Performance

This technology was accepted into EPA's SITE Demonstration Program in 1987. The developer currently is seeking a private party to co-fund a 3-to-4-month demonstration of LST technology on an organic waste.

The technology has been applied in the field over a dozen times to treat wood preservative sludges in impoundment-type LST systems. In addition, the technology has treated petroleum refinery impoundment sludges in two field-based pilot demonstrations and several laboratory treatability studies.

Remediation Costs

Cost information was not provided for this publication.

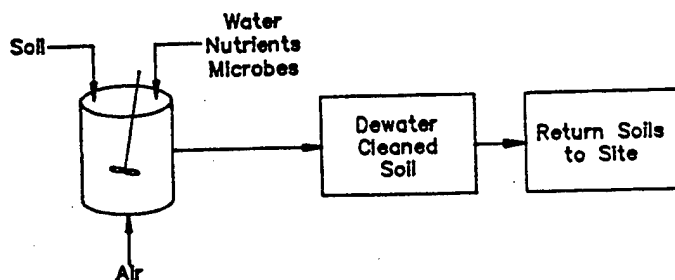
General Site Information

Site information was not provided for this publication.

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Liquid and Solids Biological Treatment



Soil Slurry-Sequencing Batch Bioreactor Explosives (TNT, RDX, HMX) in Soil

Technology Description

In this treatment process, explosives-contaminated soils and water are biologically treated in a tank or reactor. This treatment may be applied to soils contaminated with TNT, RDX, HMX, and other potential wastes associated with explosives. Contaminated soils are excavated and pre-screened to remove large rocks and debris. During the *Fill* period, the soils are mixed with water to produce a water-based slurry (typically 10-40 percent solids by weight) and pumped into the reactors. The reactors are designed and instrumented with various process controls. After the *Fill*, a chemical feed system will deliver required amounts of co-substrate, nutrients, nitrate, and Ph adjusting chemicals.

During the *React* period which follows, the mixers remain on and the microbial consortium degrades contaminants. When oxygen is serving as the exogenous electron acceptor, the aeration and mixing system is used to suspend the slurry. When nitrate is the electron acceptor, only the mixing system is used. In either case, the co-substrate serves as the primary carbon source. The time provided for the *React* cycle is dictated by the rate at which the explosive are degraded.

The mixed, treated slurry is then removed from the reactor in the *Draw* cycle and dewatered. Process water is recycled to the extent possible.

Operation of the soil slurry-sequencing batch bioreactor depends on three factors:

- Enhancement of appropriate microbial consortia;
- Operations under appropriate conditions with a suitable electron acceptor; and
- Daily replacement of a volume of soil to provide new soil for microbial processing.

This treatment technology is best suited for sites contaminated with small volumes of contaminated soil where incineration would be cost prohibitive.

Technology Performance

Previous bench-scale studies using soils contaminated with explosives from Joliet Army Ammunition Plant (JAAP) demonstrated the feasibility of this technology. Using microbial consortia isolated from JAAP, bench-scale studies showed that microbial degradation of contaminated soils could be accomplished with electron acceptors under aerobic and anoxic conditions with malate as a co-substrate. Aerobic reactors reduced TNT concentrations from about 1,300 mg/kg to less than 10 mg/kg in 15 days. Anoxic reactors achieved the same kind of reduction but at a slower rate. The same study indicated that this technology was the most suitable reactor system for full-scale implementation. A pilot-scale field demonstration using the technology was conducted in 1992.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Joliet Army Ammunition Plant is located in Joliet, Illinois. JAAP is a government-owned, contractor-operated installation currently maintained in a non-producing, standby condition. JAAP is divided into two major functional areas: a load-assemble-pack (LAP) area and a manufacturing area. The LAP area contains munitions filling and assembly lines, storage magazines, and a demilitarization area. The LAP was placed on the National Priorities List in 1989. Soils from Group 61 in the LAP area will be used in the demonstration project.

Group 61 was constructed in 1941 to support World War II efforts and has been the site of demilitarization operations for various munitions. During these operations, steam was used to remove the explosives from munitions. The solids in the contaminated process water were settled out in a sump and the overflow water was discharged into a 10-acre ridge and furrow system (evaporating pond). The primary explosive contaminant is 2,4,6-TNT with concentrations ranging from 20-14,400 mg/kg.

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Bioremediation

Vegetation-Enhanced Biodegradation TCE and PCE in Soil

Technology Description

In this process, plants are cultivated to encourage root-associated (rhizosphere) microorganisms to degrade contaminants. TCE and PCE in concentrations of 10,000 ppb are targeted. The technology also has been demonstrated for PAH compounds.

Greenhouse studies have proven the principal involved in this process. Pine trees were the most effective plant tested in these studies. Mineralization was demonstrated with radiolabels.

The process is limited, probably to about 20 feet, by the depth of penetration of the roots and/or root exudates.

Technology Performance

The process is being tested in pilot-scale field plots at DOE's Savannah River Site near Aiken, South Carolina, as part of the agency's on-going Integrated Demonstration Project. Site characterization and greenhouse studies have been completed.

Remediation Costs

Use of this process is expected to cost less than \$50,000/acre treated.

General Site Information

This process is being tested at DOE's Savannah River Site near Aiken, South Carolina.

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CHEMICAL TREATMENT



Chemical Detoxification of Chlorinated Aromatic Compounds Dioxin and Herbicides in Soil

Technology Description

This chemical detoxification of chlorinated aromatic compounds treats soils that have been contaminated with dioxin, herbicides, or other chlorinated aromatic contaminants.

The contaminated soil is excavated and a determination of the water content is made. If the water content is too high, the soil is dehydrated. Soil is placed in the reactor with the reagent and heated to 100°C to 150°C. The reagent is a 1:1:1 mixture of potassium hydroxide, polyethylene glycol, and dimethyl sulfoxide. After reaction, the reactor is drained and the soil is rinsed with clean water to remove excess reagents. Treated soil might be replaced in its original location depending upon the effectiveness of the decontamination and local environmental regulations.

Technology Performance

Demonstrations of this method achieved greater than 99.9 percent decontamination. Several advantages of this method were indicated:

- It is relatively inexpensive for contaminants at low concentrations (in the ppm range);
- The reagents can be recycled;
- The products of the decontamination are not toxic and are not biodegradable;

- Bioassay studies show that the reaction products do not bioaccumulate or bioconcentrate; they do not cause mutagenicity, nor are they toxic to aquatic organisms or mammals;
- The chlorine atoms are replaced by glycol chains producing non-toxic aromatic compounds and inorganic chloride compounds; and
- The equipment components are commercially available.

Despite the numerous advantages of this technology, it also has limitations:

- For high contaminant concentrations, in the percent range, incineration could be less expensive to use;
- Water might interfere with the reactions between the reagents and the chlorinated aromatic compounds; and
- Some chlorinated compounds, such as hexachlorophene-24, are not degraded as effectively as others.

Remediation Costs

The costs are in the range of \$100 to \$200/ton. The Naval Civil Engineering Laboratory (NCEL) reports that the costs might be on the order of \$300/yd³. The most expensive item is the reagent.

General Site Information

Small-scale pilot testing was conducted on dioxin-contaminated soil in the laboratory. Larger-scale pilots are planned for the near future by the EPA laboratory at Edison, New Jersey.

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Chemical Treatment and Immobilization

Organic Compounds, Heavy Metals, Oil, and Grease in Soil and Sludge

Technology Description

This treatment system is capable of chemically destroying certain chlorinated organics and immobilizing heavy metals. The technology mixes hazardous wastes, cement or fly ash, water, and one of 18 patented reagents commonly known as "Chloranan." In the case of chlorinated organics, the process uses metal-scavenging techniques to remove chlorine atoms and replace them with hydrogen atoms. Metals are fixed at their lowest solubility point.

Soils, sludges, and sediments can be treated *in situ* or excavated and treated *ex situ*. Sediments can also be treated underwater. Blending is accomplished in batches, with volumetric throughput rated at 120 tons/hr.

The treatment process begins by adding Chloranan and water to the blending unit, followed by the waste and mixing for 2 minutes. The cement is added and mixed for a similar time. After 12 hours, the treated material hardens into a concrete-like mass that exhibits unconfined compressive strengths (UCS) in the 1,000 to 3,000 pounds per square inch (psi) range, with permeabilities of about 10^{-9} centimeters per second (cm/sec). Results may vary. It is capable of withstanding several hundred cycles of freeze and thaw weathering.

This technology has been refined since the 1987 SITE demonstration and is now capable of destroying certain chlorinated organics and also immobilizing other wastes, including very high levels of metals. The organics and inorganics

can be treated separately or together with no impact on the chemistry of the process.

Technology Performance

This technology was demonstrated in October 1987 at a former oil processing plant in Douglassville, Pennsylvania. An Applications Analysis Report (EPA/540/A5-89/001) and a Technology Evaluation Report (EPA/540/5-89/001a) are available. A report on long-term monitoring may be obtained from EPA's Risk Reduction Engineering Laboratory.

Since the demonstration in 1987, the technology has been greatly enhanced through the development of 17 more reagent formulations that expand dechlorination of many chlorinated organics to include PCBs, ethylene dichloride (EDC), trichlorethylene (TCE), and others.

Remediation of heavily contaminated oily soils and sludges has been accomplished, as well as remediation of a California Superfund site with up to 220,000 ppm of zinc. The Canadian Government selected this process as one to test for underwater treatment of PCBs and VOCs found in sediments. A demonstration for Environment Canada is due to be completed in August 1993, in Montreal, Quebec.

Comparisons of the 7-day, 28-day, 9-month, and 22-month sample test results for the soil are generally favorable. The physical test results were very good, with UCS between 220 and 1,570 psi. Very low permeabilities were record-

ed, and the porosity of the treated wastes was moderate. Durability test results showed no change in physical strength after the wet and dry and freeze and thaw cycles. The waste volume increased by about 120 percent. However, refinements of the technology now restrict volumetric increases to the 15 to 25 percent range. Using less additives reduces strength, but toxicity reduction is not affected. There appears to be an inverse relationship between physical strength and organic contaminant concentration.

The results of the leaching tests were mixed. The Toxicity Characteristics Leaching Procedure (TCLP) results of the stabilized wastes were very low; essentially, all concentrations of metals, VOCs, and semivolatile organics were below 1 ppm. Lead leachate concentrations dropped by a factor of 200 to below 100 ppb. Volatile and semivolatile organic concentrations, however, did not change from the untreated soil TCLP. Oil and grease concentrations were greater in the treated waste TCLP (4 ppm) than in the untreated waste (less than 2 ppm).

The process can treat contaminated material with high concentrations (up to 25 percent) of oil. However, during the SITE demonstration, volatiles and base and neutral extractables were not immobilized significantly.

Heavy metals were immobilized. In many instances, leachate reductions were greater by a factor of 100.

The physical properties of the treated waste include high unconfined compressive strengths, low permeabilities, and good weathering properties.

Remediation Costs

The process, based on tests at Douglassville, Pennsylvania, was economical, with costs ranging from \$40 to 60/ton for processing heavy metals waste, and between \$75 to 100/ton for wastes with heavy organic content.

General Site Information

This technology was demonstrated at a former oil processing plant in Douglassville, Pennsylvania. The site soil contained high levels of oil and grease (250,000 ppm) and heavy metals (22,000 ppm lead), and low levels of VOCs (100 ppm) and PCBs (75 ppm).

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Combined Chemical Binding, Precipitation, and Physical Separation Heavy Metals and Radionuclides in Waters

Technology Description

This technology removes heavy metals and radionuclides from contaminated waters. In addition, it can be used to restore ground water from mining operations, treat naturally occurring radioactive materials (NORM) in water or scale from petroleum operations, and remediate man-made radionuclides stored in tanks, pits, barrels, or other containers.

The process combines the proprietary powder (RHM-1000) and a complex mixture of oxides, silicates, and other reactive binding agents, with a contaminated water stream. Selectively enhanced complexing and sorption processes form flocculants and colloids, that are removed by precipitation and physical filtration. The pH, mixing dynamics, processing rates, and powder constituents are optimized by chemical modeling studies and laboratory tests. The contaminants are concentrated in a stabilized filter and precipitate sludge, that is then dewatered. The dewatered sludge meets Toxicity Characteristic Leaching Procedure criteria and may, depending on the contaminants, be classified as non-hazardous.

The field pilot unit is skid-mounted and consists of four main components: a pump unit, a feed and eductor unit, a mixing tank, and a clarifier tank. The centrifugal pump unit can deliver up to 50 gpm to the system. Water from the pump passes through the restrictor nozzle in the feed and eductor unit, reducing the air pressure at the outlet of an attached hopper unit. RHM-1000 powder is placed in the upper hopper, which is

powered by compressed air. The upper hopper delivers a controlled and very low volume of RHM-1000 to the lower hopper. Reduced air pressure draws it into the water stream. The water passes through a two-stage mixing process and is then sent to the mixing tank. A diaphragm pump, driven by compressed air, draws water from the tank's base and re-injects it through a jet nozzle that also draws surrounding water through holes in its base. The mixed water and RHM-1000 powder pass over a weir into the clarifier tank and through a block of inclined coalescing tubes. Precipitates collect in the tank's base and are drained off. Additional conventional filters can be added to the system outflow as required. The process is designed for continuous operation and can be expanded from 25 to 1,500 gpm.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in July 1990 and was demonstrated late in 1992 at a uranium site in Texas.

Remediation Costs

Cost information was not provided for this publication.

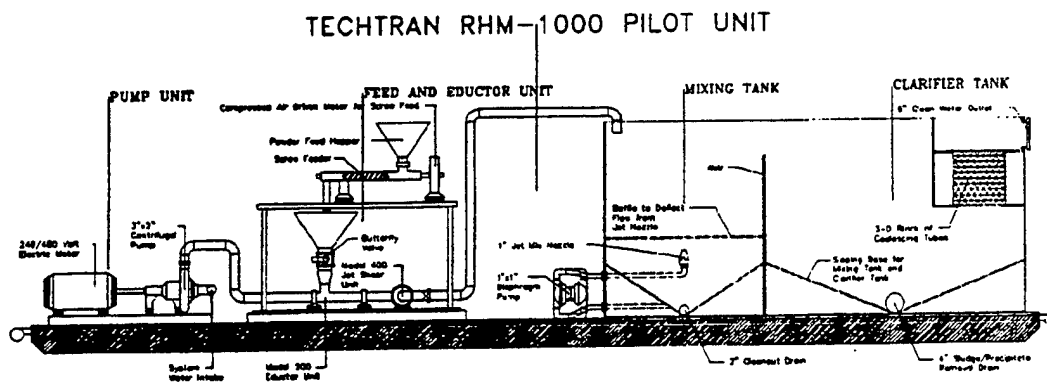
General Site Information

This technology was demonstrated at a uranium site in Texas.

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TechTran RHM-1000 Pilot Plant



perox-pure™
Fuel Hydrocarbons, Chlorinated Solvents, and PCBs in Ground Water

Technology Description

The perox-pure™ technology is designed to destroy dissolved organic contaminants in ground water or wastewater through an advanced chemical oxidation process using ultraviolet (UV) radiation and hydrogen peroxide. Hydrogen peroxide is added to the contaminated water, and the mixture is then fed into the treatment system. The treatment system contains four or more compartments in the oxidation chamber. Each compartment contains one high intensity UV lamp mounted in a quartz sleeve. The contaminated water flows in the space between the chamber wall and the quartz tube in which each UV lamp is mounted.

UV light catalyzes the chemical oxidation of the organic contaminants in water by its combined effect upon the organics and its reaction with hydrogen peroxide. First, many organic contaminants that absorb UV light may undergo a change in their chemical structure or may become more reactive with chemical oxidants. Second, and more importantly, UV light catalyzes the breakdown of hydrogen peroxide to produce hydroxyl radicals, which are powerful chemical oxidants. Hydroxyl radicals react with organic contaminants, destroying them and producing harmless by-products, such as carbon dioxide, halides, and water. The process produces no hazardous by-products or air emissions.

This technology treats ground water and wastewater contaminated with chlorinated solvents, pesticides, PCBs, phenolics, fuel hydrocarbons, and other toxic compounds at concentrations

ranging from a few thousand milligrams per liter to one microgram per liter. In cases where the contaminant concentration is greater than the technology alone can handle, the process can be combined with other processes such as air stripping, steam stripping, or biological treatment for optimal treatment results.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in July 1991. The demonstration at the Lawrence Livermore National Laboratory (LLNL) Site 300, a Superfund site, was completed in September 1992. During the demonstration, about 40,000 gal of ground water contaminated with VOCs were treated. The principal contaminants were TCE and PCE present at concentrations of about 1,000 and 100 µg/L, respectively. Ground water was pumped from two wells into a 7,500-gal bladder tank to minimize any variability in influent characteristics. In addition, cartridge filters were used to remove suspended solids greater than 3 microns from the ground water before it entered the bladder tank. Treated ground water was stored in two 20,000-gal steel tanks before being discharged.

The demonstration was conducted in three phases. Phase 1 consisted of eight runs; Phase 2 consisted of four runs, and Phase 3 consisted of two runs. The principal operating parameters of the system, hydrogen peroxide dose, influent pH, and flow rate (hydraulic retention time) were varied during Phase 1 to observe treatment system performance under different

conditions. Preferred operating conditions, those under which the concentrations of effluent VOCs were reduced below target levels at the least cost, were then determined for the system.

Phase 2 involved spiked ground water and reproducibility tests. Ground water was spiked with about 300 µg/L each of 1,1-dichloroethane (DCA), 1,1,1-trichloroethane (TCA), and chloroform. These compounds were chosen because they are difficult to oxidize and because they were not present in the ground water at high concentrations. This phase also was designed to evaluate the reproducibility of treatment system performance at the preferred operating conditions determined in Phase 1.

In Phase 3, the effectiveness of quartz tube wipers was evaluated by performing two runs using spiked ground water.

Key findings from the demonstration will be published by EPA in an Applications Analysis Report and Technology Evaluation Report. Preliminary findings include the following:

- Preferred operating conditions from Phase 1 were (1) influent hydrogen peroxide at 40 mg/L, (2) the hydrogen peroxide in influent to Reactors 2 through 6 at 25 mg/L, (3) the influent pH at 5.0, and (4) flow rate at 10 gal/min.
- During the three reproducibility runs, average removal efficiencies for chloroform, DCA, PCE, TCA, and TCE after Reactor 1 were 46.1 percent, 70.3 percent, 95.9 percent, 21.0 percent, and 98.4 percent, respectively.
- System setup and shakedown took about five days. The system required little or no attention after operating conditions were established. There were no major operational problems that affected system performance.

This technology has been applied to over 60 different sites throughout the United States, Canada, and Europe, including National Priorities List, Resource Conservation and Recovery

Act (RCRA), Department of Energy, and Department of Defense sites. These units are treating contaminated ground water, industrial wastewater, landfill leachates, potable water, and industrial reuse streams.

Remediation Costs

Economic data from three case studies indicate that ground water remediation costs for a 50-gal/min system could range from about \$7 to \$11/1,000 gal, depending on contaminated ground water characteristics. Of these, direct treatment costs for this system could range from about \$3 to \$5/1,000 gal.

General Site Information

This technology was demonstrated at the Lawrence Livermore National Laboratory (LLNL) Superfund site in Livermore, California. LLNL is a U.S. Department of Energy facility.

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Physical Separation/Chemical Extraction Radionuclides and Metals in Sediments

Technology Description

In this process, soils are screened, classified, and placed into a leaching unit with hot nitric acid. Contaminants — cesium-137, cobalt-60, and chromium — are removed from the leachate using a system of ion exchange, reverse osmosis, precipitation, or evaporation. In a similar process, contaminants are sequentially exposed to milder leachates such as oxalic acid and hydrogen peroxide. This process is designed to remove successive layers of weathering deposits from surfaces of the soil particles.

The process produces sludge from leaching and precipitation, large-grained material from the screening plant, and residuals from the other processes. Ultimate disposal options include solidification, calcining leachate, and storage of residuals.

Technology Performance

A pilot-scale test of the process was completed late in 1992 at the DOE's Idaho National Engineering Laboratory (INEL) Superfund site. Testing results indicated excellent removal efficiencies for cobalt-60 and chromium, utilizing either the sequential extraction or the hot nitric acid. Cesium-137 could be removed only with successive dissolution steps in nitric acid. Approximately 30 percent of the soil matrix was co-dissolved in order to achieve release of most of the cesium-137. A full-scale process plant will not be constructed. An Explanation of Significant Differences in the Interim Action Record of Decision has been signed.

Remediation Costs

Engineering estimates are about \$1,000/yd³ of soil treated by acid wash. Total cost of the INEL remediation project is estimated at about \$20 million.

General Site Information

The contaminated area is a warm waste pond at the INEL test reactor area, formerly used for testing of materials used in nuclear reactors. INEL is located in Idaho Falls, Idaho.

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PO*WW*ER™ Evaporation and Catalytic Oxidation VOCs and Non-volatile Organic Compounds in Ground Water

Technology Description

PO*WW*ER™ is a technology developed to treat wastewaters, such as leachates, ground waters, and process waters, containing mixtures of salts, metals, and organic compounds. The proprietary technology is a combination of evaporation and catalytic oxidation processes. Wastewater is concentrated in an evaporator by boiling off most of the water and the volatile contaminants, both organic and inorganic. Air or oxygen is added to the vapor, and the mixture is forced through a catalyst bed, where the organic and inorganic compounds are oxidized. This stream, composed of mainly steam, passes through a scrubber, if necessary, to remove any acid gases formed during oxidation. The stream is then condensed or vented to the atmosphere. If condensed, the resulting water is suitable for most uses, or for discharge. The resulting concentrated solution is either disposed of or treated further, depending on the nature of the waste.

The PO*WW*ER™ technology can be used to treat complex wastewaters that contain volatile and non-volatile organic compounds, salts, metals, and volatile inorganic compounds. Suitable wastes include leachates, contaminated ground waters, and process waters. The system can be designed for any capacity, depending on the application and the volume of the wastewater. Typical commercial systems range from 10 to 1,000 gpm.

Technology Performance

The PO*WW*ER™ technology was demonstrated under the EPA SITE Program in September 1992 at the Lake Charles Treatment Center site in Lake Charles, Louisiana. During the demonstration, a 0.25 gpm pilot-plant treated landfill leachate contaminated with VOCs, SVOCs, ammonia, cyanide, metals, and other inorganic contaminants. The system achieved a total solids concentration of about 32 to 1. VOCs, SVOCs, ammonia, and cyanide, all of which were present in the feed waste, were not detected in the product condensate. Inorganic contaminants were concentrated in the brine solution. Non-condensable gas emissions met the proposed regulatory requirements for the site.

Remediation Costs

Economic data indicate that the capital cost for a 50 gpm system is about \$4 million. Annual operating and maintenance cost at a Superfund site are estimated to be about \$3.3 million. At an annual inflation rate of 5 percent, the total cost of a project lasting 15 years is estimated to be about \$110/1,000 gal of aqueous waste treated. The total cost of a 30-year project is estimated to be about \$100/1,000 gal treated.

General Site Information

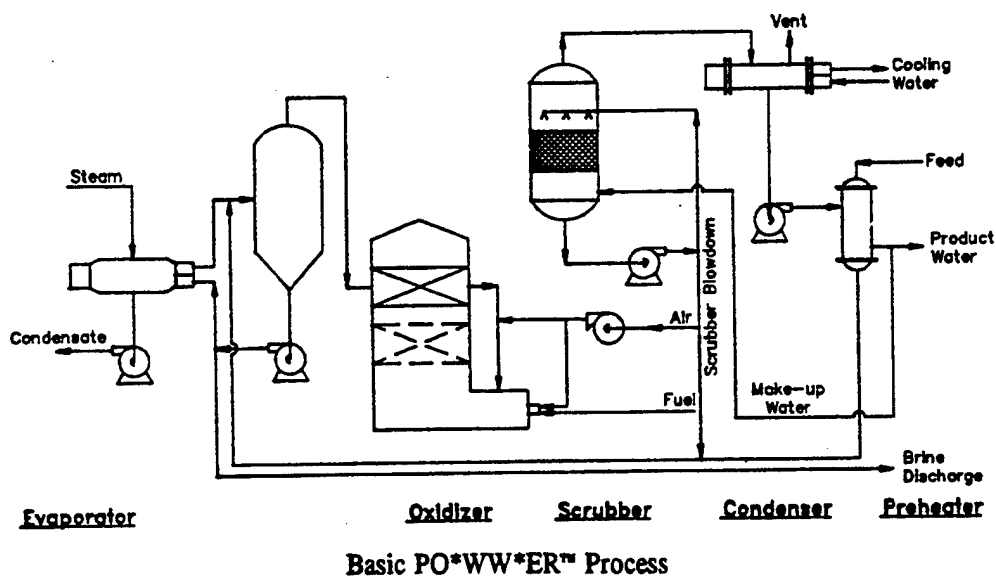
Chemical Waste Management's Lake Charles Treatment Center site is located near the cities of Sulphur and Lake Charles in Southwest Louisiana. The site has facilities that include a

hazardous waste landfill, a high-capacity stabilization unit, and drum managing and decanting facilities. During the SITE demonstration, about 590 gal of unspiked landfill leachate from the site were treated.

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SAREX Chemical Fixation Process

Low-Level Metals and Organics in Soil and Sludge

Technology Description

The SAREX chemical fixation process is a thermal and chemical reactive (fixation) process that removes VOCs and SVOCs, and the remaining constituents of organic and inorganic sludge materials in a stable matrix. The process uses specially prepared lime and proprietary, non-toxic chemicals (a reagent blend) mixed proportionally to catalyze and control the reactions. The treated product displays chemical properties which conform to toxic EPA standards for resource recovery and site restoration. The product also exhibits high structural integrity, with a fine, granular, soil-like consistency, of limited solubility. It is free flowing until compacted (50 to 80 psi), isolating the remaining constituents from environmental influences.

Depending on the characteristics of the waste material, it may be covered with a liquid neutralizing reagent that initiates the chemical reactions and helps prevent vapor emissions. If required, the waste material may be moved to the neutralization (blending) tank where a "make-up" reagent slurry is added, depending on material characteristics. The waste is placed on the feed hopper.

The reagent is measured and placed on the transfer conveyor so that the reagent and waste mixture would advance to the single-screw homogenizer, where it is thoroughly blended to a uniform consistency. The reagent blend reacts exothermally with the hazardous constituents to initiate the removal of the VOCs and SVOCs. The process, now about 70 percent complete,

continues in the multi-screw, jacketed, non-contacting processor for curing (a predetermined curing time allows reactions to occur within a controlled environment). In the processor, the mixture can be thermally processed at a high temperature to complete the process. The processed material exits the processor onto a discharge conveyor for movement into specially designed sealed transport containers.

Contaminant loss into the air (mobility) during processing is eliminated by use of a specially designed vapor recovery system and processed prior to release into the air. Dust particles are removed in a baghouse, and the vapors are routed through a series of water scrubbers, which cool the vapors (below 120°F) and remove any condensates. The vapors then pass through two demisters and a positive displacement blower to remove additional condensates. A freon chilling unit (37°F or 0°F) cools the remaining vapors, which are sent to a storage tank. The final vapor stream is polished in two charcoal vapor packs before being emitted into the air.

The SAREX process is applicable to a wide variety of organic and inorganic materials. These include sludges that contain high concentrations of hazardous constituents, with no upper limit of oil or organic content. No constituents interfere with the fixation reactions, and water content is not an obstacle, although there may be steaming caused by the exothermic reactions. The following material types can be processed by the SAREX system:

- Large crude oil spills
- Refinery sludges
- Hydrocarbon-contaminated soils
- Lube oil acid sludges
- Tars

In addition, metals are captured within the treated matrix and will pass the TCLP. This proves to be advantageous, because most on-site cleanup programs focus on sludge ponds or impoundments that have received many different types of compounds and debris over several years.

Technology Performance

During the development of the SAREX CFP technology, data has been gathered from laboratory analysis, process demonstrations, and on-site projects. Samples of sludges from two ponds were analyzed for surface and bottom characteristics. After treatment of the samples, the products were analyzed in powder and molded pellet form.

A field demonstration was conducted during 1987 at a midwest refinery by treating approximately 400 cubic yards of lube oil acid sludges. Two projects each were completed in the midwest, California, and Australia.

An EPA SITE Program demonstration is scheduled for completion this year.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This process has been demonstrated at sites in the midwest, California, and Australia.

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Chemical Treatment

Solar Detoxification VOCs in Ground Water

Technology Description

This technology exposes VOCs in ground water to sunlight in the presence of a non-toxic catalyst (TiO_2), causing the VOCs to break down into non-toxic compounds, such as carbon dioxide, chloride ions, and water.

The process involves a system consisting of a pumping station, a set of solar reflectors, and the reactors, which are narrow Pyrex pipes that hold the contaminated water and the catalyst. During operation, contaminated water is drawn into the pumping station where the flow rate through the solar detoxification system is adjusted, the pH is lowered, and the catalyst is added. The solar reflectors concentrate the sun's light, focus it directly on the Pyrex reactors, and oxidize the VOCs. After moving through the reactors, the water is cooled and its pH is readjusted as necessary. At this point, based on monitoring results, the ground water can be recirculated through the system or the catalyst can be filtered out and the water sent on for secondary treatment for legal discharge to the environment within permitted levels.

Technology Performance

This system was field tested at Lawrence Livermore National Laboratory in California in 1991. The project clearly demonstrated the destruction of TCE-contaminated ground water to non-detectable levels. While the demonstration did not require full capacity, the system used was capable of treating more than 7,000 gpd.

About 200 lbs of used TiO_2 , containing 2 ppm chromium, was produced during treatment of some 50,000 gallons of ground water. Due to the chromium content, this would require further treatment as a hazardous waste.

While there were few operational problems, the test confirmed that salts in ground water (chlorides, nitrates, bicarbonates) absorb UV photons and hydroxyl radicals, which can reduce process efficiency.

Remediation Costs

No cost information available.

General Site Information

The field demonstration was conducted at Lawrence Livermore National Laboratory (LLNL), Livermore, California. During World War II, LLNL was the site of a naval air station with responsibilities for training and aircraft maintenance. At that time, TCE and other VOCs were used to clean engine parts, and large quantities of these compounds found their way into the ground water beneath the site.

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Xanthate Treatment

Heavy Metals in Ground Water and Wastewater

Technology Description

This is a process in which metals are removed through precipitation. Metal contaminants in the water exchange with Na^+ ions contained by the xanthated material to form an insoluble complex. The heavy metals-laden material can then be removed from solution by sedimentation and filtration.

Currently, hydroxide precipitation is used extensively in the treatment of heavy metal-contaminated ground waters and wastewater. Xanthate treatment offers many advantages over hydroxide precipitation, including the following:

- A higher degree of metal removal;
- Less sensitivity to pH fluctuation (metal xanthates do not exhibit amphoteric solubilities);
- Less sensitivity to the presence of complexing agents;
- Improved sludge dewatering properties; and
- The capability of the selective removal of metals.

Technology Performance

The U.S. Army Engineer Waterways Experiment Station (WES) has performed bench- and pilot-scale treatability studies on xanthate precipitation. Studies are currently being conducted to evaluate the use of xanthates for metal segregation and recycling.

Remediation Costs

Costs will vary with application, but treatment costs should be similar to currently used precipitation methods.

General Site Information

This process has been tested at the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi.

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THERMAL TREATMENT



Anaerobic Thermal Processor

PCBs, Chlorinated Pesticides, and VOCs in Soil and Refinery Wastes

Technology Description

The anaerobic thermal processor (ATP) is a thermal desorption process. It heats and mixes contaminated soils, sludges, and liquids in a special rotary kiln that uses indirect heat. The unit desorbs, collects, and recondenses hydrocarbons and other pollutants found in contaminated materials. The unit also can be used in conjunction with a dehalogenation process to destroy halogenated hydrocarbons through a thermal and chemical process.

The kiln portion of the system contains four separate internal thermal zones: preheat, retort, combustion, and cooling. In the preheat zone, water and VOCs vaporize. The vaporized contaminants and water are removed under a slight vacuum to a vapor cooling system for condensation. As condensation occurs, light hydrocarbon vapors separate into liquid, oil, and non-condensable gas phases.

From the preheat zone, the hot solids and heavy hydrocarbons pass through a proprietary sand seal to the retort zone. The sand seal allows the passage of solids and inhibits the passage of gases, including contaminants, from one zone to the other. Concurrently, hot treated soil from the combustion zone enters the retort zone through a second sand seal. This hot treated soil provides the thermal energy necessary to desorb the heavy contaminants. Heavy oils vaporize in the retort zone, and thermal cracking of hydrocarbons forms coke and low molecular weight gases. The vaporized contaminants are removed under a slight vacuum to the gas handling system. After cyclones remove dust

from gases, the gases are cooled, and condensed oil is separated into its various fractions.

The coked soil passes through a third sand seal from the retort zone to the combustion zone. Coke is burned, along with auxiliary fuel, and some of the hot soil is recycled to the retort zone. The remainder is sent to the cooling zone. Flue gases from the combustion zone are treated prior to discharge. The flue gas treatment system consists of the following units set up in series: a cyclone and baghouse for particle removal, a wet scrubber for removal of acid gases, and a carbon adsorption bed for removal of trace organic compounds.

The combusted soil that enters the cooling zone is cooled in the annular space between the outside of the preheat zone and the outer shell of the kiln. Here, the heat from the soils is transferred to the soils in the retort and preheat zones. The cooled treated soil and coke exiting the cooling zone is quenched with water, then transported by conveyor to a storage pile.

When the ATP is used to dechlorinate contaminants, the contaminated soils are sprayed with an oil mixture containing an alkaline reagent and polyethylene glycol, or other reagents. The oil acts as a carrier for the dehalogenation reagents. In the unit, the reagents dehalogenate or chemically break down chlorinated compounds, including PCBs.

The technology can be used for oil recovery from tar sands and shales, dechlorination of PCBs and chlorinated pesticides in soils and sludges, separation of oils and water from

refinery wastes and spills, and general removal of hazardous organic compounds from soils and sludges.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in March 1991. Full-scale demonstrations were conducted at the Wide Beach Development Superfund site in Brant, New York, in 1991 and at the Outboard Marine Corporation site in Waukegan, Illinois, in 1992.

Results from these demonstrations included the following:

- The ATP unit removed over 99 percent of the PCBs in the contaminated soil, resulting in PCB levels below the desired cleanup concentration of 2 ppm.
- The ATP did not appear to create dioxins or furans.
- No volatile or semivolatile organic degradation products were detected in the treated soil. There were also no leachable VOCs or SVOCs detected in the treated soil.
- No operational problems affecting the ATP's ability to treat the contaminated soil were observed.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Full-scale demonstrations have been conducted at the Wide Beach Development Superfund site in Brant, New York, and at the Outboard Marine Corporation site in Waukegan, Illinois.

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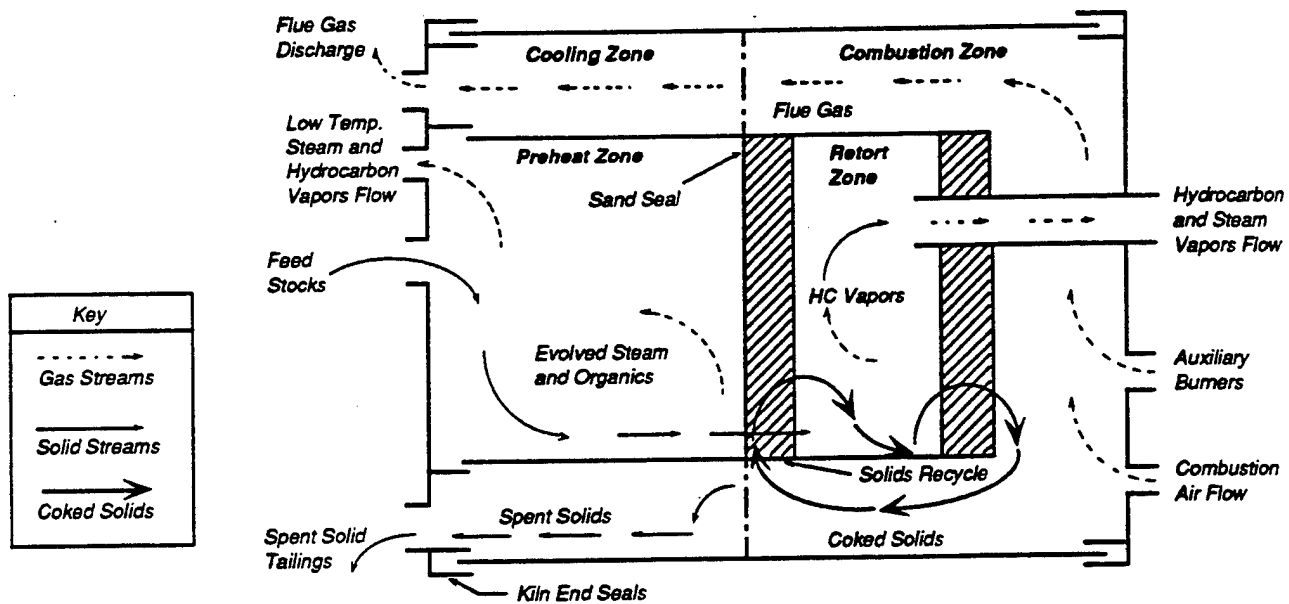
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Anaerobic Thermal Processor (ATP)



Cyclone Furnace Organics and Metals in Soil

Technology Description

This technology is designed to decontaminate wastes containing both organic and metal contaminants. The cyclone furnace retains heavy metals in a non-leachable slag and vaporizes and incinerates the organic materials. The treated soils resemble natural obsidian (volcanic glass), similar to the final product from vitrification.

The furnace is a horizontal cylinder and is designed for heat release rates greater than 450,000 British thermal units (Btu)/foot³ (coal) and gas temperatures exceeding 3,000°F. Natural gas and preheated primary combustion air (820°F) enter the furnace tangentially. Secondary air (820°F), natural gas, and the synthetic soil matrix (SSM) enter tangentially along the cyclone barrel (secondary air inlet location). The resulting swirling action efficiently mixes air and fuel and increases combustion gas residence time. Dry SSM has been tested at pilot-scale feed rates of both 50 and 200 lb/hr. The SSM is retained on the furnace wall by centrifugal action; it melts and captures a portion of the heavy metals. The organics are destroyed in the molten slag layer. The slag exits the cyclone furnace (slag temperature at this location is 2,400°F) and is dropped into a water-filled slag tank where it solidifies into a non-leachable vitrified material. A small quantity of the soil also exits as fly ash from the furnace and is collected in a baghouse.

This technology may be applied to high-ash solids (such as sludges and sediments) and soils containing volatile and non-volatile organics and

heavy metals. The less volatile metals are captured more readily in the slag. The technology would be well-suited to mixed waste soils contaminated with organics and non-volatile radionuclides (such as plutonium, thorium, uranium). Because vitrification has been listed as a Best Demonstrated Achievable Technology (BDAT) for arsenic and selenium wastes, the cyclone furnace may be applicable to these wastes as well.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in August 1991 and was demonstrated at the developer's facility in 1991, using synthetic soil matrices spiked with heavy metals, semivolatile organics, and radionuclide surrogates. The process was demonstrated using an EPA-supplied, wet SSM spiked with lead, cadmium, chromium, anthracene, dimethylphthalate, and simulated radionuclides—bismuth, strontium, and zirconium. Almost 3 tons of SSM were processed during the demonstration at a feed rate of 170 lb/hr.

The vitrified slag TCLP leachabilities were 0.29 mg/L for lead, 0.12 mg/L for cadmium, and 0.30 mg/L for chromium (all pass the EPA TCLP limits). Almost 95 percent of the non-combustible SSM was incorporated into the slag. Greater than 75 percent of the chromium, greater than 88 percent of the bismuth, and greater than 97 percent of the zirconium were captured in the slag. Volume reduction was 29 percent on a dry basis. Destruction and removal efficiencies (DRE) for anthracene and

dimethylphthalate were greater than 99.997 percent and 99.998 percent, respectively. Stack particulates were 0.001 grams per dry standard cubic feet (g/dscf) at 7 percent oxygen, which is below the RCRA limit of 0.08 g/dscf. Carbon monoxide and total hydrocarbons in the flue gas were 6.0 ppm and 8.3 ppm, respectively. The simulated radionuclides were immobilized in the vitrified slag as measured using the American Nuclear Society 16.1 Method.

The demonstration results have been documented by EPA in an Applications Analysis Report (EPA/540/AR-92/017). The report also is available from NTIS (PB93-122315).

Remediation Costs

Economic analysis, performed by an EPA contractor as part of the SITE demonstration, estimated costs of \$528/ton of contaminated soil for a system treating 20,000 tons of contaminated soil at 3.3 tons/hr.

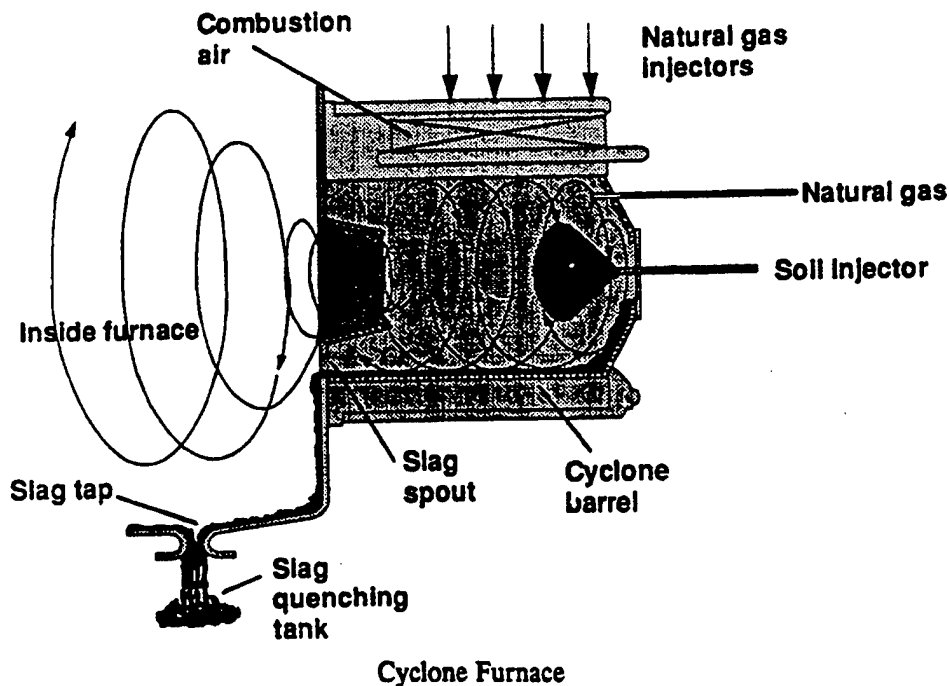
General Site Information

This technology was demonstrated at the Babcock and Wilcox Company's facility in Alliance, Ohio.

Contacts

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Dynamic Underground Stripping

Organics in Concentrated Underground Plumes (*In Situ* Treatment)

Technology Description

This technology is used to treat underground leaks of organic contaminants, such as those from underground storage tanks, which can be a source of ground water contamination. The technology heats the contaminated soil with a site-specific combination of steam injection and three-phase electrical heating to speed the contaminant removal process. Because it is a highly energetic process, real-time monitoring is used for process control and to ensure that contaminants are not inadvertently mobilized or moved to unanticipated areas.

Injection wells are installed in permeable areas surrounding the concentrated plume, and one or more extraction wells are installed in the center. The extraction wells are pumped to depress the water table in the center of the pattern. Then, steam is injected through the perimeter wells to heat and sweep the formation. Injection pressure is controlled according to depth, and is lower in shallow applications.

As the steam is forced into the wells, the earth is heated to the boiling point of water. The advancing pressure front displaces ground water toward the extraction well. Near the steam-condensate front, organics are distilled into the vapor phase, transported to the front, and condensed there. The zone of advancing steam displaces the condensed liquids toward the recovery wells. When the steam reaches the wells, vacuum extraction is used as the removal mechanism.

At a selected time in the process, electrode assemblies placed in the impermeable layers of the ground are turned on, passing 480 V current through the formation at up to several hundred amperes per electrode. This heats clay and fine-grained sediments, causing any water and contaminants trapped within to vaporize and be forced into the steam zones to be swept toward the extraction wells. Electrical heating may be followed by one or more additional steam injection phases for contaminant removal and to keep permeable zones hot as ground water returns.

Technology Performance

A demonstration of this technology at a gasoline spill site at Lawrence Livermore National Laboratory (LLNL) in California, was conducted during 1993. The demonstration involved six injection wells around the perimeter of the spill zone and three extraction wells, used to maintain the required liquid and vapor removal rates. Preliminary results indicate the removal of more than 5,000 gal of gasoline from the lower part of the spill during nine weeks of extraction.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Approximately 17,000 gal of gasoline were spilled at the LLNL site. An estimated 5,000 gal were trapped beneath the water table because of a 30-ft rise in the water table. The remainder of the spill was in the vadose zone.

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Thermal Treatment

High-Temperature Thermal Processor Organics in Solids and Sludges

Technology Description

The high temperature thermal processor is a thermal desorption system that can treat solids and sludges contaminated with organic constituents. The system consists of material feed equipment, a thermal processor, a particulate removal system, an indirect condensing system, and activated carbon beds.

Waste from the feed hopper is fed to the thermal processor, which consists of a jacketed trough that houses two intermeshing, counter-rotational screw conveyors. The rotation of the screws moves material through the processor. A molten salt eutectic, consisting primarily of potassium nitrate, serves as the heat transfer media. This salt melt has heat transfer characteristics similar to those of oils and allows maximum processing temperatures of up to 850°F. The salt melt is non-combustible and poses no risk of explosion, and potential vapors are non-toxic. The heated transfer media continuously circulates through the hollow flights and shafts of each screw and also circulates through the jacketed trough. An electric or fuel oil/gas-fired heater is used to maintain the temperature of the transfer media. Treated product is cooled to less than 150°F for safe handling.

A particulate removal system (such as a cyclone or quench tower), an indirect condensing system, and activated carbon beds are used to control off-gases. The processor operates under slight negative pressure to exhaust the volatilized constituents (moisture and organics)

to the off-gas control system. An inert atmosphere is maintained in the headspace of the processor using air lock devices at the feed inlet and solids exit and an inert carrier gas (such as nitrogen) to maintain an oxygen concentration of less than 3 percent. The oxygen and organic content of the off-gas are continuously monitored as it exits the processor.

Entrained particulate matter is collected and combined with the treated solids on a batch basis. The volatilized moisture and organics are subsequently condensed and decanted. A mist eliminator minimizes carry-over of entrained moisture and contaminants after the condenser. Any remaining non-condensable gases are passed through activated carbon beds to control volatile organic compound emissions.

This system can treat soils, sediments, and sludges contaminated with VOCs and SVOCs, including PCBs. Work to date has focused primarily on RCRA wastes from the petroleum refinery industry. Testing indicates the system has the potential to treat cyanide-contaminated materials from petroleum refineries and manufactured gas plant sites. With the exception of mercury, the process is not suitable for treating heavy metals. Wastes must be prescreened to a particle size of less than 1 inch before treatment.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in June 1991. A commercial-scale system is operating at a Gulf

Coast refinery, and the developer is offering on-site testing using a mobile pilot-scale system with a capacity of 0.5 tons/hr. The SITE demonstration is being conducted at the Niagara-Mohawk Power Company, a manufacturing gas plant site, in Harbour Point, New York.

Remediation Costs

Cost information was not provided for this publication.

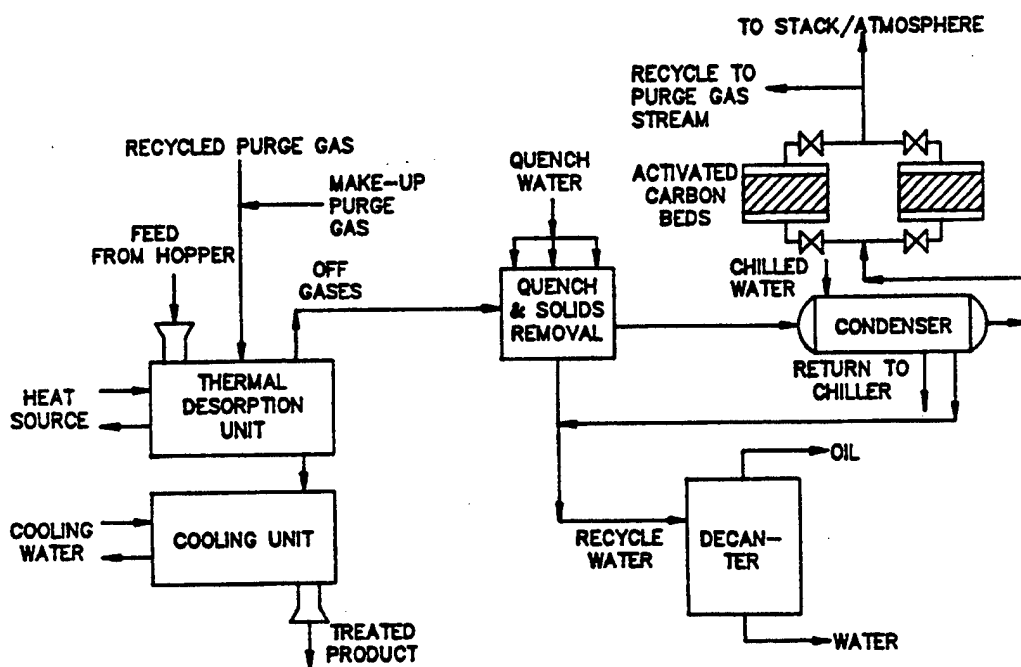
General Site Information

The SITE Program demonstration is being conducted at the Niagara-Mohawk Power Company site in Harbour Point, New York.

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High Temperature Thermal Processor



Thermal Treatment

HRUBOUT® Process

Volatile and Semivolatile Organic Compounds in Soils (*In Situ* Treatment)

Technology Description

The HRUBOUT® Process removes VOCs and SVOCs from contaminated soils. Heated air is injected into the soil below the zone of contamination, evaporating the soil moisture and removing volatile and semivolatile hydrocarbons. As the water evaporates, soil porosity and permeability is increased, further facilitating the air flow at higher temperatures. Non-volatiles are removed in place by slow oxidation at the higher temperature ranges.

Injection wells are drilled in predetermined distribution patterns to a depth below the contamination. The wells are equipped with steel casing, perforated at the bottom and cemented into the hole above the perforations. This base is then cemented into the hole. Heated, compressed air is introduced at temperatures up to 1,200 °F, and the pressure is slowly increased to force the soil water up uniformly. As the air progresses upward through the soil, the moisture is evaporated, taking with it the VOCs and SVOCs. A surface collection system captures the exhaust gases under negative pressure and conducts them to a thermal oxidizer where the hydrocarbons are thermally destroyed at 1,500°F.

The air is heated in a 2.9 million-Btu/hr adiabatic burner. The incinerator has a rating of 3.1 million Btu/hr. The air blower can deliver up to 8,500 lbs/hr. The units employ a fully modulating fuel train run with natural gas or propane. All equipment is mounted on custom-designed mobile units and operates 24 hours/day.

The process is capable of treating soils in the vadose zone contaminated with halogenated or non-halogenated VOCs and SVOCs at a wide concentration range. Gasoline, solvents, diesel oil, jet fuel, heating oil, crude oil, lubricating oil, creosotes, and hydraulic oils are the primary hydrocarbons suitable for treatment. There is no residual output from the treatment site, eliminating any potential future liability.

Technology Performance

This technology was accepted into the EPA SITE Program in 1992. The demonstration was conducted late in 1992 at Kelly Air Force Base in San Antonio, Texas.

Pilot-testing in a sandy clay loam indicated that the process begins volatilizing gasoline in the vadose zone in 14 to 16 days and diesel in 17 to 19 days. The technology required 13 days to vaporize the soil water. After these tests were conducted, equipment development increased heated air injection capability by 70 percent.

Additional research and development has shown that excavated contaminated soils may be treated by distributing the soils over a horizontal perforated piping grid. The process injects the pressurized heated air via the grid system, collects the resulting vapors beneath an impermeable covering, and directs those vapors into the thermal oxidizer. A containerized version of the above process also has been developed. Future containers may be large enough to treat 40 yd³ of contained soil.

Additional patents for broadened applications of this technology are pending. The process was approved by the Texas Water Commission in 1991.

Remediation Costs

Cost information was not provided for this publication.

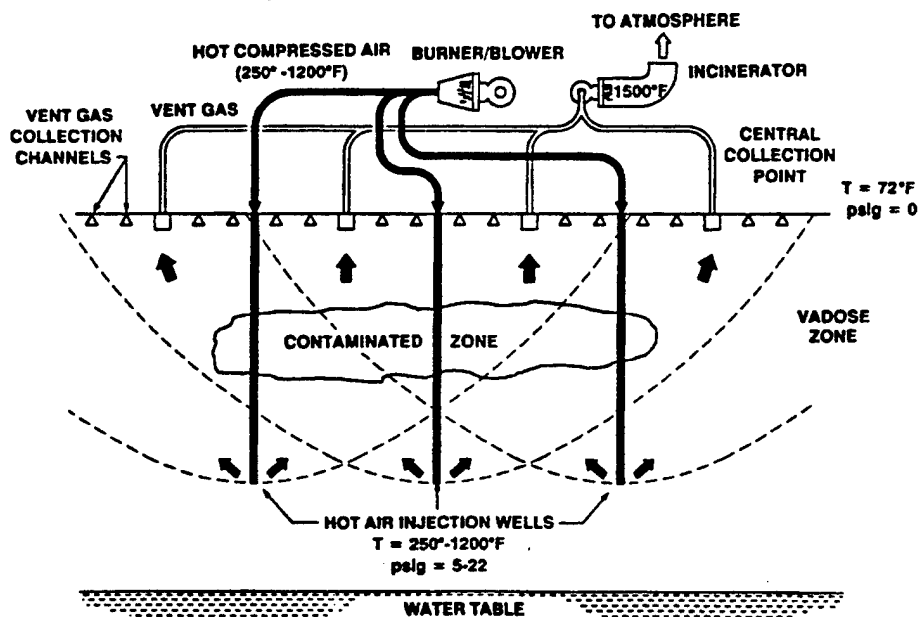
General Site Information

This process was demonstrated at Kelly Air Force Base in San Antonio, Texas.

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HRUBOUT® Process



Thermal Treatment

In Situ Vitrification Organics and Inorganics in Soil and Sludge

Technology Description

This *in situ* vitrification (ISV) process uses an electric current to melt soil or sludge at extremely high temperatures (1,600°C to 2,000°C), thus destroying organic pollutants by pyrolysis. Inorganic pollutants are incorporated within the vitrified mass, which has glass properties. Water vapor and organic pyrolysis by-products are captured in a hood, which draws the contaminants into an off-gas treatment system that removes particulates and other pollutants.

The vitrification process begins by inserting large electrodes into contaminated zones containing sufficient soil to support the formation of a melt. An array (usually square) of four electrodes is placed to the desired treatment depth in the volume to be treated. Because soil typically has low electrical conductivity, flaked graphite and glass frit are placed on the soil surface between the electrodes to provide a starter path for electric current. The electric current passes through the electrodes and begins to melt soil at the surface. As power is applied, the melt continues to grow downward, at a rate of 1 to 2 inches/hr. The large-scale ISV system melts soil at a rate of 4 to 6 tons/hr.

The mobile ISV system is mounted on three semitrailers. Electric power is usually taken from a utility distribution system at transmission voltages of 12.5 or 13.8 kilovolts. Power also may be generated on-site by a diesel generator. The electrical supply system has an isolated ground circuit to provide appropriate operational safety.

Air flow through the hood is controlled to maintain a negative pressure. An ample supply of air provides excess oxygen for combustion of any pyrolysis products and organic vapors from the treatment volume. Off-gases are treated by quenching, pH controlled scrubbing, dewatering (mist elimination), heating (for dewpoint control), particulate filtration, and activated carbon adsorption.

Individual settings (placement of electrodes) may grow to encompass a total melt mass of 1,000 tons and a maximum width of 35 feet. Single-setting depths as great as 25 feet are considered possible. Depths exceeding 19 feet have been achieved with existing large-scale ISV equipment. Adjacent settings can be positioned to fuse to each other and to completely process the desired volume at a site. Stacked settings to reach deep contamination are also possible. Void volume present in particulate materials (20 to 40 percent for typical soils) is removed during processing, reducing the waste volume.

The ISV process can be used to destroy or remove organics and to immobilize inorganics in contaminated soils or sludges. In saturated soils or sludges, water is driven off at the 100°C isotherm moving in advance of the melt. Water removal increases energy consumption and associated costs. Also, sludges must contain a sufficient amount of glass-forming material (non-volatile, non-destructible solids) to produce a molten mass that will destroy or remove organic pollutants and immobilize inorganic pollutants. The ISV process is limited by (1) individual void volumes in excess of 150 ft³, (2)

rubble exceeding 20 percent by weight, and (3) combustible organics in the soil or sludge exceeding 5 to 10 weight percent, depending on the heat value.

Technology Performance

The ISV process has been operated for test and demonstration purposes at pilot scale 22 times and at large scale 10 times. Sites have included Geosafe's test site and the DOE's Hanford Nuclear Reservation, Oak Ridge National Laboratory, and Idaho National Engineering Laboratory. More than 130 tests at various scales have been performed on a broad range of waste types in soils and sludges. The EPA SITE Program demonstration is being conducted during 1993 at the Parsons/ETM Superfund site in Grand Ledge, Michigan. Geosafe is currently doing further technology testing before any field remediation work.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology has been demonstrated at a variety of sites, including Geosafe's test site in Kirkland, Washington, and the DOE's Hanford Nuclear Reservation in Richland, Washington, Oak Ridge National Laboratory in Oak Ridge, Tennessee, and Idaho National Engineering Laboratory in Idaho Falls, Idaho.

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***In Situ* Vitrification**

Organics, Inorganics, and Radionuclides in Soils

Technology Description

This *in situ* vitrification (ISV) process fixes fission products and immobilizes or destroys mixtures of hazardous chemicals in soils. This technology can be applied to radionuclides, heavy metals, and hazardous organic-contaminated soil.

ISV is the conversion of contaminated soil into a durable glass and crystalline waste form through melting the soil by joule heating. Contaminants are destroyed by or immobilized in molten glass (melted soil). Soil is melted by electrical energy from electrodes that are placed in the ground. Off-gas from this process is treated by conventional off-gas treatment methods.

This technology has a number of benefits. Specifically, ISV may safely immobilize or destroy both radioactive and hazardous chemicals before they impact the ground water or other ecosystems. It is applicable to soils contaminated with fission products, transuranics, hazardous metals, and hazardous organics. It reduces the risk to the public by immobilizing or destroying radioactive and hazardous materials in the soil. Finally, *in situ* treatment poses a lower potential risk to workers than traditional treatments because contaminants are not brought to the surface. This technology, however, has not yet been demonstrated at depths beyond twenty feet.

The ISV technology can be applied to a wide range of soil types and contaminants. Melt depths of approximately 5 meters are considered

the practical limit for most sites at this time. However, additional research is being conducted to ultimately achieve melt depths of up to 10 meters. There are no practical limits for inorganic contaminants; current processing systems are designed to process up to 8 wt. percent organics based on heat loading considerations. High moisture soils can generally be processed, but saturated soils with free flowing ground water would require the use of methods to minimize ground water recharge. With use of electrode feeding technology (vertically moveable electrodes), inclusions such as scrap metals and buried piping can be processed without concern of electrical short circuits.

Technology Performance

Recent field-scale demonstrations have been conducted at the DOE's Hanford Reservation and Oak Ridge National Laboratory. During a large-scale demonstration at the Hanford site, a liquid waste disposal crib constructed of wooden timber was vitrified producing a monolith of over 800 tons in size. Contamination in soils in and below the crib contained heavy metals, such as lead and chromium, and radionuclides, including an estimated 900 mCi of strontium-90 and 150 mCi of cesium-137. The demonstration was conducted in 1990. Coring of the block was completed in 1991. Key results from the study indicated the following:

- The ISV process maintained an 87 percent on-line operating efficiency during the test;
- The off-gas treatment system easily accommodated the additional off-gas and heat

- loads from the thermal decomposition of the crib's wooden timbers;
- Analyses of cores taken from the monolith revealed a homogeneous composition due to the convective mixing currents that occur in the melt;
- The resulting glass and crystalline product easily passed TCLP criteria;
- Chromium and lead retention in the melt was greater than 99.99 percent, and the retention in the melt for cesium-137 was greater than 99.98 percent;
- Leach testing (monolithic static tests in water at 90°C) indicated that the vitrified product was comparable in durability to both high-level waste borosilicate glasses and natural analogs such as granite; and
- Melt depth was limited to 4.3 meters (the bottom of the crib) and was hindered by a cobble layer beneath the crib.

A second ISV field demonstration was conducted in May 1991 on a one-quarter-scale liquid waste disposal trench containing 10 mCi of cesium-137. The trench was designed to simulate the liquid waste disposal trenches at Oak Ridge National Laboratory, many of which contain thousands of Curies of cesium-137 and strontium-90. The test was conducted over a five-day period and achieved a melt depth of about 2.75 meters, exceeding expectations for the pilot-scale system. Key results included the following:

- Approximately 97.6 wt. percent of cesium was retained in the melt. A particulate filter system installed on the off-gas line was used to effectively prevent the balance of cesium that was volatilized during the vitrification process (2.4 wt. percent) from reaching the off-gas treatment trailer;
- Surrounding soils were determined to be free of cesium contamination indicating that no outward migration occurred;
- Post-test evaluations of the vitrified product revealed that the cesium partitioned in the glass phases of the block rather than in the crystalline phases or at phase boundaries;

- No volatilization of strontium-90 or plutonium-239/240 was detected, and >99.993 percent of these non-volatile radionuclides were retained in the melt;
- The use of added rare earth tracers (cerium, lanthanum, and neodymium) as surrogates for transuranic isotopes led to estimated melt retentions of >99.9995 percent; and
- Leach testing of crushed vitrified product (-100 to +200 mesh) in water at 90°C revealed that the normalized releases of the vitrified material are typically less than high-level waste borosilicate glasses.

Additional large-scale ISV performance data will be obtained by the Geosafe Corporation. The company was expected to commence commercial ISV operations in 1993, including large-scale equipment operational tests and two multiple-setting remedial demonstrations.

Remediation Costs

Costs of approximately \$300 to \$450/ton of soil, exclusive of costs for mobilization and demobilization of the process equipment, are expected.

General Site Information

Demonstrations of this technology have been conducted at DOE's Hanford Reservation in Richland, Washington, and Oak Ridge National Laboratory in Oak Ridge, Tennessee.

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Low-Temperature Thermal Aeration (LTTA®) Organics in Soils, Sediments, and Sludges

Technology Description

This technology is a low-temperature desorption process that removes organic compounds from contaminated soils by heating the soils up to 800°F. The main components of the process include (1) a materials dryer, (2) a pug mill, (3) two cyclonic separators, (4) a baghouse, (5) a wet Venturi scrubber, (6) a liquid-phase granular activated carbon (GAC) column, and (7) two vapor-phase GAC beds.

A front-end loader transports contaminated soils to feed hoppers, which release the soil onto a conveyor belt. The conveyor belt transports the contaminated soils into the materials dryer. Contaminated soils in the materials dryer are heated by a parallel-flow hot air stream heated by a propane/fuel oil burner. The materials dryer is a rotating drum equipped with longitudinal flights for soil mixing.

Processed soil is discharged to an enclosed pug mill where water is added to cool it and to control fugitive dust emissions. Treated soil is released onto a discharge conveyor and stockpiled. The stockpiled soil is tested on site to confirm that it meets cleanup goals and then disposed or retreated as required.

The exhaust air stream from the materials dryer, containing vaporized organic contaminants and airborne soil particulates, is treated with a series of standard air pollution control devices before being vented to the atmosphere.

The process can remove VOCs and SVOCs, organochlorine pesticides (OCPs),

organophosphorous pesticides (OPPs), and total petroleum hydrocarbons (TPHs) from soils, sediments, and some sludges. The technology has been used at full scale to remove VOCs such as benzene, toluene, PCE, TCE, and dichloroethylene (DCE); SVOCs such as acenaphthene, chrysene, naphthalene, and pyrene; OCPs such as DDT and its metabolites; OPPs such as ethyl parathion and methyl parathion; and TPHs. The developer has reported removal efficiencies of greater than 99 percent for VOCs at concentrations up to 5,400 mg/kg, greater than 92 percent for pesticides up to 1,500 mg/kg, and 67 to 96 percent for SVOCs up to 6.5 mg/kg.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1992. A demonstration was performed on soils contaminated with OCPs at a pesticide site in Arizona in September 1992. Key findings from the demonstration include:

- The process met the specified cleanup criteria for the site, a sliding scale criteria correlating the concentrations of DDT-family compounds (DDD, DDE, DDT) with concentrations of toxaphene. The maximum allowable pesticide concentration in the treated soil were 3.52 mg/kg of DDT-family compounds and 1.09 mg/kg of toxaphene.
- Residual levels of all the pesticides in the treated soil generally were near or below to the laboratory detection limit, except 4,4-DDE which was found at residual concentrations of 0.1 to 1.5 mg/kg. Removal

efficiencies for pesticides found in the feed soil at quantifiable concentrations, except 4,4-DDE, were greater than 99.8 percent. The removal efficiency for 4,4-DDE was just over 90.2 percent.

- The process did not generate dioxins or furans as products of incomplete combustion or thermal transformation.
- Some thermal breakdown products were formed within the process. These included acetone, acrylonitrile, benzoic acid, benzyl alcohol, benzaldehyde, dihydrofuranone, phenol, and methyl phenol. These products were removed extensively in the untreated scrubber liquor and the vapor-phase GAC beds. The stack emissions included some of the compounds at low concentrations.
- The average emissions rate for compounds detected at quantifiable levels in the stack gas included 4,4-DDE at 0.000043 lb/hr, chloromethane at 0.020 lb/hr, benzene at 0.053 lb/hr, and toluene at 0.008 lb/hr. The presence of acetonitrile and acrylonitrile in the stack emissions is being confirmed.
- The process performed efficiently with no down time during the demonstration. A staff of six to eight is required for operation, including site supervisors, an excavation crew, support staff, and laboratory chemists for next day confirmation testing. The process layout requires space for eight to 10 flat-bed trailers and sufficient area (150 ft x 150 ft) to stage feed and treated soils.

Remediation Costs

Cost information was not provided for this publication.

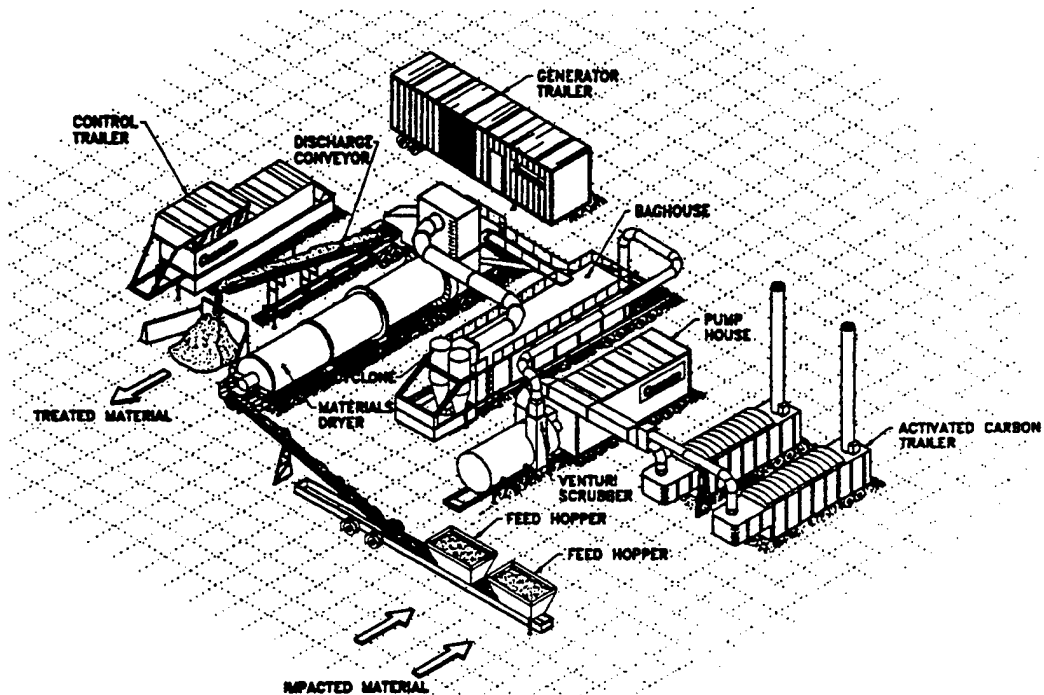
General Site Information

This technology was demonstrated at a pesticide site in Arizona. The full-scale system has been used in remediation of six sites, including three Superfund sites.

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Low Temperature Thermal Aeration



Low-Temperature Thermal Stripping Volatile Organic Compounds in Soil

Technology Description

Low-temperature thermal stripping removes VOCs such as chlorinated solvents and fuels from soils. The technology is applicable to contaminated soils associated with fire training pits, burn pits, spills, and lagoons. Contaminants having boiling points as high as 500°C have been removed from soils.

In 1985, the U.S. Army Toxic and Hazardous Materials Agency sponsored the development of a low-temperature thermal stripping process which used a Holo-Flite screw thermal processor. Contaminated soil is fed through an opening at the top of the system, called the soil feed hopper. The soil falls into the main part of the system, or thermal processor. The thermal processor consists of two separate but identical units, each containing four large, hollow screws. The screws are 18 inches in diameter and 20 feet long. As the screws turn, they churn the soil, breaking it up and pushing it from the feed end of the processor to the discharge end.

Simultaneously, hot oil is pumped through the inside of the screws. The constant churning of the soil and movement of hot oil up and down the length of the screws heat the soil and volatilize the VOCs. Additional heat is provided by the walls of the processor, called the trough jacket, which also contains flowing hot oil. The thermal processor heats up to a maximum of about 650°F.

This method does, however, have a number of limitations: this is a media transfer technique rather than a destructive technique; treatment of

the gaseous effluent prior to discharge might be required, depending upon local regulations; bench-scale evaluation should be conducted before pilot testing or implementation (the equipment for the bench-scale test is available and will fit in a standard laboratory hood); lower explosive limits must be considered when treating soils contaminated with flammable solvents; an inert gas such as nitrogen might be considered as an alternative to air to reduce the risk of combustion or explosion; and since this is a low-temperature method, metal contaminants will not be removed.

Technology Performance

The results from a pilot-scale field demonstration of this technology were extremely positive. Eighteen days of formal testing were completed in 22 consecutive calendar days. During this period, more than 10,000 pounds of contaminated soils were processed. Upon completion of the formal testing, 10 additional days of testing were conducted to optimize system performance. During this period, more than 5,000 pounds of contaminated soils were processed. A comparison of the VOCs measured in the processed soil and stack gas indicated that a greater than 99.9 percent destruction and removal efficiency was achieved. A summary of the soil concentrations and maximum VOC removal efficiencies is provided in Table 1. Stack emissions were in compliance with all Federal and state regulations (including those for VOCs, hydrogen chloride (HCL), carbon monoxide (CO), and particulates). After processing, regulatory

approval was granted to dispose of the treated soils on site as backfill.

Remediation Costs

To treat a site containing 15,000 to 80,000 tons of contaminated soil, the optimally-sized process costs would be \$74/ton and \$160/ton, respectively, without flue gas treatment. If afterburner exhaust gases are treated prior to discharge, the respective costs are \$87/ton and \$184/ton.

General Site Information

A large-scale pilot test was conducted at Letterkenny Army Depot, Chambersburg, Pennsylvania. The demonstration was conducted between August 5 and September 16, 1985. The feed soils were excavated from lagoons in the K-1 Area which received organic liquids from industrial operations at the Depot. The contaminants were TCE, DCE, PCE, and xylene.

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Table 1. Summary of Soil VOC Concentrations and Maximum VOC Removal Efficiencies

VOC	Feed Soil Average (ppm)	Concentrations Maximum (ppm)	Maximum Removal Efficiency
Dichloroethylene	83	470	>99.9
Trichloroethylene	1,673	19,000	>99.9
Tetrachloroethylene	429	2,500	>99.9
Xylene*	64	380	>99.9
Other VOCs	14	88	>99.9
Total VOCs	2,263	22,438	>99.9

* Xylene is not classified as a VOC since its boiling point is approximately 140°C. However, it was included in this study to evaluate the effectiveness of this technology on higher boiling point semivolatile compounds.



Thermal Treatment

Low-Temperature Thermal Treatment (LT³) Volatile and Semivolatile Organics in Soil

Technology Description

The basis of the LT³ technology is the thermal processor, an indirect heat exchanger used to dry and heat contaminated soils. The process includes three main steps: soil treatment, emissions control, and water treatment. Equipment used in the process is mounted on three tractor trailer beds for transport and operation, and it requires an area of about 5,000 ft².

The thermal processor consists of two covered troughs that house four intermeshed screw conveyors. The covered troughs and screws are hollow to allow circulation of hot oil, providing indirect heating of the soils. Each screw moves the soil through the processor and thoroughly mixes the material.

The heating of the soil to 400°F to 500°F evaporates contaminants from the soil. Soil is discharged from the thermal processor into a conditioner where a water spray cools it and minimizes dust emissions. A fan draws desorbed organics from the processor through a baghouse filter. Depending on the contaminant characteristics, dust from the filter may be retreated, combined with treated materials, or drummed separately for on-site disposal. Exhaust gas from the filter is drawn through an air-cooled condenser to remove most of the water vapor and organics. It then is passed through a second refrigerated condenser and is treated by carbon adsorption.

The condensate streams from the LT³ system are treated to separate light and heavy organic

phases from the water phase. The water is treated by carbon adsorption until it is free of contaminants. Treated condensate often is used for soil conditioning, and only the organic phases are disposed off site.

This technology can be applied to soils contaminated with VOCs and SVOCs. Soils contaminated with coal tar, drill cuttings (oil-based mud), No. 2 diesel fuel, JP-4 jet fuel, leaded and unleaded gasoline, petroleum hydrocarbons, halogenated and non-halogenated solvents, and PAHs have been treated using this technology.

Technology Performance

A full-scale demonstration was conducted at Tinker Air Force Base in Oklahoma City, Oklahoma, in 1989. The demonstration was designed to remove jet propulsion fuel (JP-4) and chlorinated organic compounds, such as TCE, from contaminated soils. The only modification to the basic system was the addition of a scrubber system to control acid gas emissions.

The demonstration showed conclusively that the technology was effective in reducing the concentration of not only JP-4 but also all compounds originally specified in the Test Plan. All cleanup level goals could be met by heating the processed soil above 215°F. This was a considerably lower temperature than anticipated. As a result, all cleanup goals were met while processing soil at rates 25 percent in excess of

the design capacity. The treatment capacity was 18,000 to 20,000 lbs/hr.

The demonstration was discontinued when PCBs were discovered in the feed and processed soils, because the system had not been designed to process PCBs.

This technology was accepted into the EPA SITE Demonstration Program in September 1991 and demonstrated at the Anderson Development Company (ADC) Superfund site in Adrian, Michigan. The site was contaminated with VOCs, SVOCs, and 4,4-methylenebis (2-chloroaniline) (MBOCA). Feed preparation for the sludge at the site included lime and ferric chloride addition, followed by filter press dewatering to a moisture content of 14 percent to 44 percent. During the demonstration, contaminated sludge was heated to above 500°F for a residence time of 90 min. The system throughput was about 2.1 tons/hr. Key findings include the following:

- The system removed VOCs to below method detection limits (less than 0.060 mg/kg for most compounds).
- The system achieved MBOCA removal efficiencies greater than 88 percent; concentrations in the treated sludge ranged from 3.0 to 9.6 mg/kg.
- The system decreased the concentrations of all SVOCs in the sludge, with two exceptions. An increase in phenol concentration most likely was due to chemical transformations during heating. A minor leak of heat transfer fluid, containing triphenylene, probably caused the apparent increase in chrysene concentration.
- Dioxin and furans were formed in the system, but the 2,3,7,8-TCDD isomer was not detected in treated sludge.
- Stack emissions of non-methane total hydrocarbons increased from 6.7 to 11 ppm by volume during the demonstration; the maximum emission rate was 0.2 lb/day. The maximum particulates emission rate was 0.02 lb/day, and no chlorides were measured in stack gases.

Remediation Costs

Based on the demonstration at Tinker Air Force Base, the unit cost for processing and decontaminating soil with similar contaminants is \$86/ton soil at an average processing rate of 8 tons/hr. Total estimated costs, including mobilization and demobilization, to process 5,000 tons would be \$116/ton. Fixed costs for mobilization, start up, and demobilization would be approximately \$150,000.

General Site Information

This technology was demonstrated at Tinker air force Base in Oklahoma City, Oklahoma, and at the Anderson Development Company Superfund site in Adrian, Michigan.

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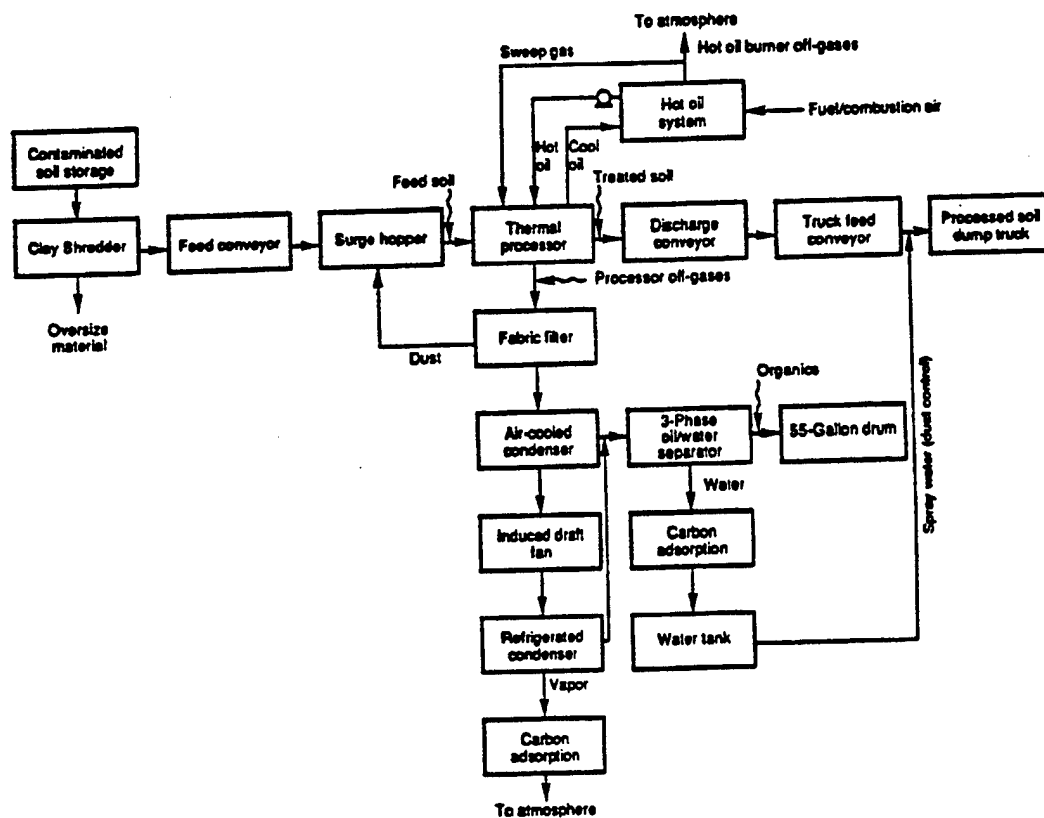
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Schematic diagram of the LT³⁰ system



Molten Salt Oxidation Process

Radionuclides, Organics, Oils, Graphite, Chemical Warfare Agents, Explosives in Liquids and Solids

Technology Description

The Molten Salt Oxidation (MSO) Process is carried out in a highly reactive oxidizing and catalytic medium. It uses a sparged bed of turbulent molten salt such as sodium carbonate at 800°C to 1,000°C with waste and air introduced beneath the surface of the molten salt. Generally, the heat of oxidation of the waste keeps the salt molten. The off-gas, containing carbon dioxide, steam, nitrogen, and un-reacted oxygen is cleaned of particulates by passing the gas through standard filters before discharging to the atmosphere.

MSO has a high treatment potential for radioactive and hazardous forms of high-heating liquids (organic solvents, waste oils), low-heating value liquids (high-halogen content organic liquids), other wastes (pesticides, herbicides, PCBs, chemical warfare agents, explosives, propellants, infectious wastes), and gases (VOCs and acid gases). By virtue of the latter, MSO could replace conventional wet-scrubbers as a superior dry-scrubber system for use with incinerators. The typical residence time is two seconds for the treatment of wastes by the MSO Process.

Wastes containing heavy metals are converted to oxides and retained in the melt. Organic solids and other combustible materials are destroyed, but MSO is not suitable for direct treatment of inert solids, such as soils and rubble. However, MSO can treat the extracted residuals of commercially available soils pretreatment technologies such as vapor extraction, solvent

extraction, thermal desorption, and base-catalyzed dechlorination. Carbon has been destroyed in all of the process demonstrations, including graphite oxidation and coal gasification.

Ash and the reaction products of acid gases and salt are retained in the molten salt. The MSO Process has been tested at 900°C for the destruction of solid combustible waste-bearing plutonium at TRU levels (>100 mCi/g). Measurable amounts of plutonium downstream of the oxidizer have shown that 99.9 percent of the plutonium remains in the melt.

The final waste form is a product of the spent salt disposal or recycle subsystem. In the destruction of chlorinated waste compounds, the melt becomes unreactive as the salt converts to approximately 90 percent sodium chloride (NaCl). The NaCl can be discarded unless it is contaminated with radionuclides. These can be extracted from the disposable salt by ion exchange chemistry coupled with biosorption techniques. Otherwise, when the salt is reusable but contains ash and possibly metal products, conventional dissolution and fractional filtration techniques with radionuclide extraction apply.

Technology Performance

Fundamental theoretical studies, experimental investigations, and demonstrations were supported by DOE and Rockwell International for about 20 years until 1982 when it was determined that MSO offered no cost advantage

over incineration. Prior to 1982, Rockwell had conducted bench-scale unit (1 to 2 lb/hr feed rate) tests on chlordane and hexachlorobenzene or EPA as well as a variety of other wastes in other programs. In these programs, Rockwell conducted bench-scale tests to demonstrate the destruction of PCBs for the Canadian Electric Association. Using the Rockwell bench-scale unit, Edgewood Arsenal personnel in 1976 demonstrated the high-efficiency destruction of the chemical warfare agents VX, GB, and mustard. In June 1993, the Committee on Alternative Chemical Demilitarization Technologies reported on MSO as one of the viable alternatives to incineration for the destruction of stockpiled chemical warfare agents. Rockwell conducted tests on a pilot-scale unit (270 lb/hr feed rate) to demonstrate the destruction of hazardous chemicals such as chlordane and hexachlorobenzene for EPA. The largest Rockwell MSO unit (2,000 lb/hr feed rate) was built and operated for DOE in 1973 to demonstrate MSO as a coal gasification technology.

Remediation Costs

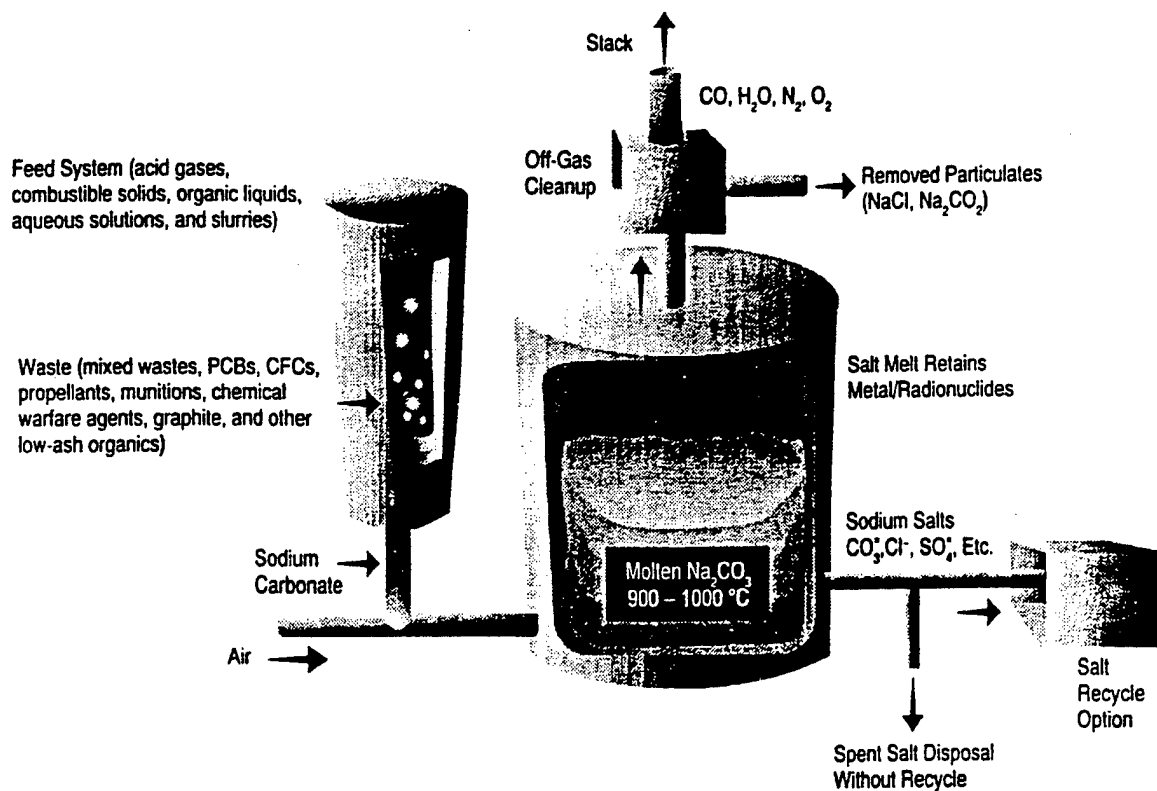
Molten salt oxidation costs are very specific to the type of waste and size of equipment. Costs as low as \$500/ton are possible. No firm cost information is available for other applications of MSO as a primary treatment system or as an incinerator off-gas dry-scrubber system. The DOE currently is engaged in a five-year MSO project plan which is expected to begin yielding that information.

General Site Information

The DOE five-year MSO project plan leads to commercial-scale operation of an MSO pilot plant at the Oak Ridge Reservation in Tennessee by 1997. Rockwell International is the principal industry partner. Prototype treatability tests of mixed (radioactive and hazardous) waste are being conducted at several DOE installations: Energy Technology Engineering Center (ETEC); Oak Ridge National Laboratory, and Los Alamos National Laboratory. ETEC recently completed destruction of 50 gallons of mixed waste hydraulic oils contaminated with Cs-137, Sr-90, and Co-60. At the Alberta (Canada) Special Waste Treatment Center Incinerator Research Facility, a prototype MSO unit designed to treat incinerator flue gas will be operated to evaluate the effectiveness of MSO as a dry-scrubber for controlling gas emissions from incinerators.

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Chemical (Partial Listing)	Destroyed (%)
PCB	6 - 9's
Para-arsanilic acid	>5 - 9's
Chloroform	>5 - 9's
Trichloroethane	>5 - 9's
Diphenylamine HCL	>5 - 9's
Nitroethane	>4 - 9's
HCB	9 - 9's
Chlorodane	7 - 9's
VX	>7 - 9's
GB	>8 - 9's
Mustard	>6 - 9's
Waste Oil With TCE	>6 - 9's

The Molten Salt Oxidation (MSO) Process



Thermal Treatment

Plasma Arc Vitrification Organics and Metals in Soils and Sludge

Technology Description

Plasma Arc Vitrification occurs in a plasma centrifugal furnace by a thermal treatment process where heat from a transferred plasma arc torch creates a molten bath that detoxifies the feed material. Solids melt and are vitrified in the molten bath at 2,800°F to 3,000°F. Metals are retained in this phase which, when cooled, forms a non-leachable, glassy residue which meets TCLP criteria.

Waste material is fed into a sealed centrifuge where it is heated to 1,800°F by the plasma torch. Organic material is evaporated and destroyed almost immediately.

Off-gas travels through a gas/slag separation chamber to a secondary combustion chamber where it remains at more than 2,000°F for more than 2 seconds. The gas then flows through an off-gas treatment system.

The off-gas treatment system removes particulates, organic vapors, and volatilized metals. Off-gas monitoring verifies that applicable environmental regulations are met. The design of the off-gas treatment system depends on the waste material.

Inorganic material is reduced to a molten phase that is uniformly heated and mixed by the centrifuge and the plasma arc. Material can be added in-process to control slag quality. When the centrifuge is slowed, the molten material is discharged as a homogeneous, non-leachable glassy slag into a mold or drum in the slag collection chamber.

The entire system is hermetically sealed and operated below atmospheric pressure to prevent leakage of process gases. Pressure relief valves connected to a closed surge tank provide relief if gas pressures in the furnace exceed safe levels. Vented gas is held in the tank and recycled into the furnace.

The technology is most appropriate for mixed waste, transuranic waste, chemical plant residues and by-products, soils containing heavy metals and organics, incinerator ash, munitions, sludge, and hospital waste.

Technology Performance

The EPA SITE Program demonstration was conducted in 1991 at DOE's Component Development and Integration Facility in Butte, Montana. During the demonstration, the furnace processed approximately 4,000 lbs of waste. The waste consisted of soil with heavy metals from the Silver Bow Creek Superfund site, spiked with 28,000 ppm zinc oxide and 1,000 ppm hexachlorobenzene and mixed in a 90-to-10 weight ratio with No. 2 diesel oil. All feed and effluent streams were sampled. The Applications Analysis Report (EPA/540/A5-91/007) has been published. Key results include the following:

- Hexachlorobenzene was at or below detection limits in all off-gas samples (minimum DRE ranged from 99.9968 percent to 99.9999 percent);
- The treated material met TCLP standards for organic and inorganic constituents;

- The treated material contained a high percentage of metals in the feed soil;
- Particulates in the off-gas exceeded the regulatory standard (the system is being modified accordingly); and

Remediation Costs

According to EPA's Applications Analysis Report, the unit cost of this technology depends on the waste feed rate to the furnace. For a feed rate of 500 lb/hr and an on-line percentage of 70 percent, the cost is estimated to be \$1,816/ton; for a 2,200 lb/hr feed rate, the cost would be \$757/ton.

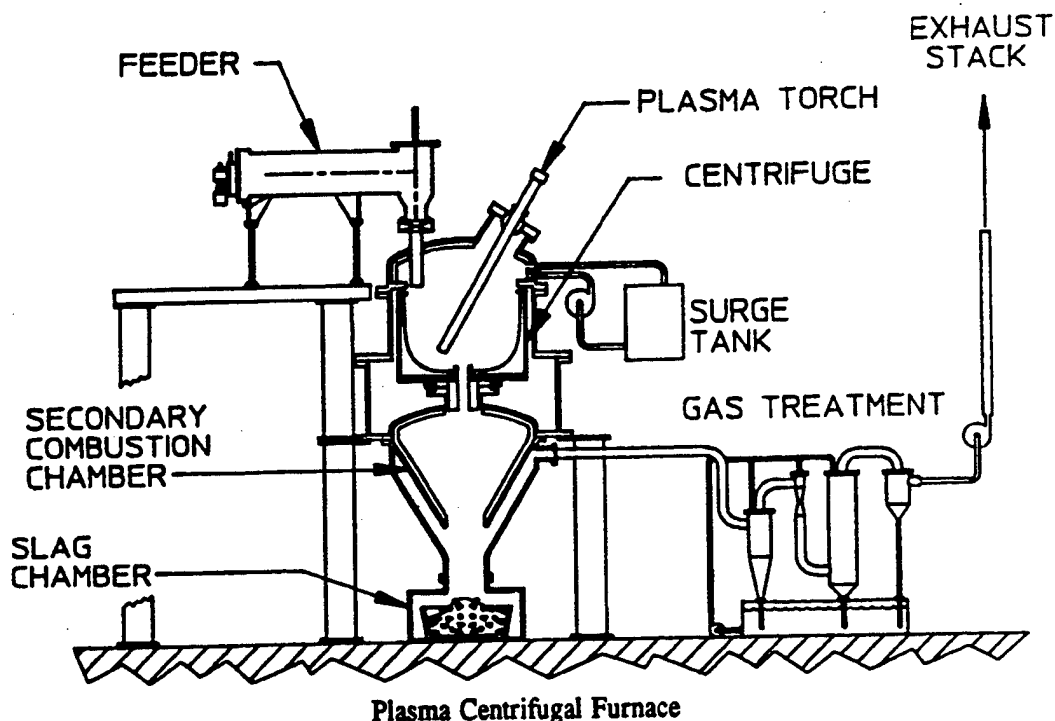
General Site Information

This technology was demonstrated at DOE's Component Development and Integration Facility in Butte, Montana.

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Radio Frequency (RF) Thermal Soil Decontamination Solvents and Volatile and Semivolatile Petroleum in Soils (*In Situ* Treatment)

Technology Description

The radio frequency (RF) thermal soil decontamination process removes volatile hazardous waste materials through *in situ* radio frequency heating of the soil and volatilization of the hazardous substances. This technology can be applied to fire training pits, spills, and sludge pits containing solvents and volatile and semivolatile petroleum.

Radio frequency heating is performed by the application of electromagnetic energy in a medically approved radio frequency band. The energy is delivered by electrodes placed in holes drilled through the soil. The mechanism of heat generation is similar to that of a microwave oven and does not rely on the thermal properties of the soil matrix. The power source for a three-row (ground-excitor-ground) single module electrode array is a 45 kw electric generator. The exact frequency of operation is selected after evaluation of the dielectric properties of the soil matrix and the size of the area requiring treatment. The gases and vapors formed in the soil matrix can be recovered at the surface or through the electrodes used for the heating process. Condensation and collection of the concentrated vapor stream is used to capture the contaminant above ground. The system consists of four components: the RF energy deposition electrode array; a RF power generator, electrical transmission, monitoring, and control system; a vapor extractions and containment system; and a gas and liquid condensate handling and treatment system.

This technology has a number of advantages:

- Demonstrations have shown higher than 90 percent reduction of hazardous hydrocarbons from soils;
- Contaminants are recovered in a relatively concentrated form without dilution from large volumes of air or combustion gases;
- This is an *in situ* method; soil does not have to be excavated; and
- All equipment is portable.

Limitations of this technology include:

- High moisture or presence of ground water in the treatment zone will result in excessive power requirements to heat the soil; and
- The method may or may not be used if large buried metal objects are in the treatment zone.
- Cool down may cause backflow of surrounding contaminants into the treated core of depression.

Technology Performance

The pilot-scale field demonstration in 1985 at Volk Field Air National Guard Base, Camp Douglas, Wisconsin, produced positive results:

- 94 to 99 percent decontamination of a 500 ft³ block of soil was achieved during a 12-day period. Ninety-seven percent of semivolatile hydrocarbons and 99 percent of volatile aromatics and aliphatics were removed;
- Contaminant removal at the 2-meter depth, the fringe of the heated zone, exceeded 95 percent;

- The 70 to 76 percent contaminant reduction in the immediate area outside the heated zone indicates that there was no net migration of contaminant from the heated area to the surrounding soil; and
- Substantial removal of high boiling contaminants can be achieved at temperatures significantly lower than their boiling point. This occurs due to the long residence time provided at lower temperatures and steam distillation provided by the native moisture.

Remediation Costs

It is estimated that the treatment cost will vary between \$28 to \$60/ton of soil. Based on bench-scale tests, it is estimated that the treatment of a 3-acre site to a depth of 8 feet containing 12 percent moisture raised to a temperature of 170°C would cost \$42/ton. The treatment of such a site would require about one year. The initial capital equipment investment for full-scale projects is estimated to be about

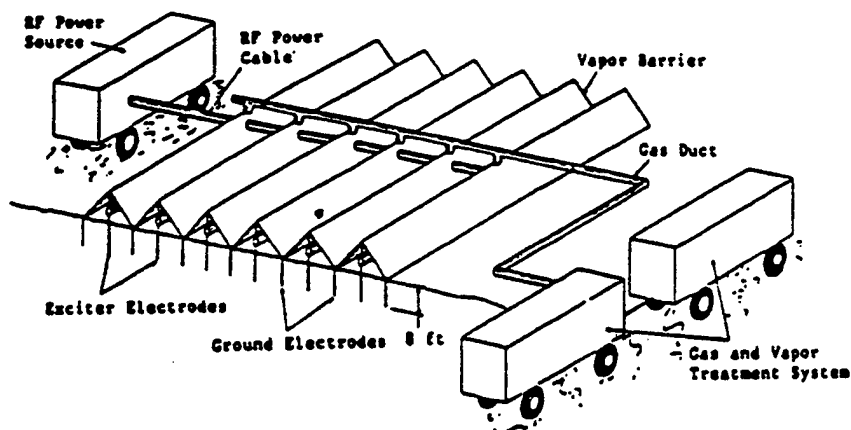
\$1.5 million. Power requirements are approximately 500 kilowatt-hours/yd³ to reach a temperature of 150°C.

General Site Information

A bench-scale pilot test (volume <20 drums) has been conducted at ITT Research Institute facilities. A full-scale demonstration was completed in seven feet of sandy soil at Volk Field (ANGB), Wisconsin, during October 1989. Another pilot-scale demonstration was conducted in 1993 at Kelly AFB, San Antonio, Texas, in clay soil 10 to 30 feet deep.

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RF Thermal Soil Decontamination



Six-Phase Soil Heating VOCs in Soils (*In Situ* Treatment)

Technology Description

This technology removes VOCs as vapors from contaminated soil. Six electrodes are placed in a circle surrounding a central vent. Six-phase current, each electrode receiving a single phase, is applied to the electrodes. Resistive heating dissipates the electrical energy in the contaminated zone, and vapor is withdrawn from the central vent as in conventional soil vapor extraction (SVE).

Compared with SVE, six-phase heating accelerates remediation. By raising the soil temperature, the vapor pressure of VOCs increases which, in turn, accelerates their removal. If the temperature increase is sufficient, six-phase heating also may allow cost-effective remediation of SVOCs by soil vapor extraction.

Applying this technology requires additional equipment and increases electrical usage. Further development work may be required to address safety concerns and design approaches for sites with underground pipes or utilities, large quantities of buried metal debris, or other conductive objects.

Site geology must be amenable to the installation of electrodes, and sufficient soil moisture must be maintained near the electrodes to avoid excessive drying which reduces electrical heating.

The technology produces no waste, but, as with conventional SVE and bioventing, off-gases must be treated or collected prior to atmospheric

release. Proper design of vents in conjunction with covers that may be placed on the surface of the soil generally is sufficient to ensure that soil off-gases are safely contained during operation.

Technology Performance

This technology is currently being demonstrated at a contaminated site on DOE's Hanford Reservation as part of the agency's VOCs at Arid Sites Integrated Demonstration Program.

Remediation Costs

Although the cost is dependent on the soil and moisture content of the soil, it is estimated that this technology costs \$30 to \$60/yd³ of soil cleaned.

General Site Information

This technology is slated for demonstration at DOE's Hanford Reservation in Richland, Washington. The Hanford Site, located in southeastern Washington State, is an area of approximately 600 square miles that was selected in 1943 for producing nuclear materials in support of the United States' effort in World War II. Hanford's operations over the last 40+ years have been dedicated to nuclear materials, electrical generation, diverse types of research, and waste management. Some of these operations produced aqueous and organic wastes that were discharged to the soil column.

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Thermally Enhanced Vapor Extraction VOCs in Soils (*In Situ* Treatment)

Technology Description

Organic waste landfill disposal cells, fire training pits, and chemical production processes often co-disposed a wide spectrum of organic chemicals (from low boiling point organic solvents to very high boiling point oils). These mixtures are difficult to remediate by vacuum vapor extraction technology due to the low mass removal rates. Innovative *in situ* soil heating technologies combined with *in situ* soil vapor extraction can increase the mass removal rates and reduce the cost of *in situ* remediation of difficult, high boiling point organic waste mixtures.

Three rows of electrodes are placed through the treatment zone (tri-plate array configuration) down to a depth of 25 feet. The center row electrodes are connected as the excitor (energy input) source and the two exterior rows are used as ground/guard electrodes to help contain the input energy to the treatment zone. Next, surface hardware connecting the electrodes is installed. Two dual purpose vacuum vapor extraction wells/electrodes are installed as part of the excitor array. A vacuum blower and off-gas treatment system provide for the removal of the heated soil contaminants.

Resistive heating technology passes power-line frequency (60 Hz) through the soil using the conductive path of the residual soil water. Power-line frequency energy input is controlled through a multi-tap transformer to allow for the changing impedance of the soil as soil water is removed. Voltages begin at about 200 V and can be increased in steps up to 1,600 V. Water

addition to the excitor electrodes is necessary to moderate the increased soil resistance caused by removal of the soil water. This technology vaporizes the added water into steam and enhances contaminant removal. When the temperature nears 100°C, the resistive heating energy input becomes constrained by the increased soil resistance (lack of residual soil water as a current conducting path). At this point, it is not effective to continue with the resistive heating mode, and switching to radio frequency (RF) heating is indicated.

RF heating uses high frequency microwaves (2 to 20 MHz) to heat the soil by dielectric heating. The RF energy is transmitted through the soils without using residual soil water as the conductive path. Energy deposition is a function of the frequency applied and the dielectric features of the soil medium. Frequency selection is based on tradeoffs of the wave penetration depth (lower frequencies penetrate further) and the dielectric constant of the soil profile. Typical frequencies used are around 6.78 MHz. The energy output from the RF transmitter is passed through a network of capacitors to match the impedance of the soil in the treatment zone to the output of the power transmitter. This hardware is necessary to minimize the energy reflected from the soil and maximize the energy absorbed by the soil. With adjustment of the transmitter frequency and matching network, soil heating can continue to 250°C or higher.

Technology Performance

RF heating has been successfully demonstrated at Volk Field Air National Guard Base at Camp Douglas, Wisconsin; Basin F at Rocky Mountain Arsenal, Colorado; and Kelly Air Force Base in San Antonio, Texas. A demonstration combining the using of resistive heating technology and RF heating is scheduled for the fall of 1993 at an organic waste disposal cell at the Chemical Waste Landfill at DOE's Sandia National Laboratory in Albuquerque, New Mexico.

Remediation Costs

Full-scale treatment costs are estimated to be \$15 to \$30/ton depending on the soil moisture content (5 to 20 percent) and treatment temperature (100°C to 250°C).

General Site Information

This technology will be demonstrated at the Chemical Waste Landfill at DOE's Sandia National Laboratory in Albuquerque, New Mexico.

Contacts

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Vitrification Furnace

Residues from Incineration of Municipal Wastes

Technology Description

This technology is used to treat residues from incineration or municipal wastes. The residues are melted to form a glassy slag and a metallic phase using a portion of the electrical energy recovered from consuming the wastes. The density of the resulting slag triples that of the residue, and the melted metallic fraction is 10 times more dense than the residue. In addition, the vitrified products appear to be environmentally benign, as is typical of glasses, and the vitrified products may have some economic value as aggregate in cement and as construction fill material.

A Memorandum of Understanding (MOU) between the U.S. Bureau of Mines and the American Society of Mechanical Engineers (ASME) has enabled an experimental program to vitrify the residues from incinerators burning municipal wastes. The experimental program currently is being conducted at the Bureau's Albany Metallurgy Research Center in Albany, Oregon.

The Bureau's vitrification furnace is a state-of-the-art electric arc furnace with water-cooled roof and sidewalls. The corrosive nature of the molten incinerator residues rules out conventional refractory-lined furnaces for this application. A dedicated feeder and off-gas treatment system complete the facility.

Technology Performance

In recent melting tests to fine-tune the facility, about 20,000 lbs of residues were melted.

These materials included combined bottom and fly ash from three municipal solid waste (MSW) incinerators, bottom ash from a sewage sludge incinerator, and fly ash from an incinerator burning refuse-derived fuel (RDF). The combined MSW residues and the RDF fly ash produced black glasses not unlike natural obsidian, whereas the sewage sludge produced a crystalline product.

An extended test, in which more than 80,000 lbs of these incinerator residues were melted in a continuous 100-hr process, confirmed the previous results. Comprehensive characterization and chemical analyses of the as-received residues were conducted prior to the melting tests. Similar analyses of the melted residues were conducted, along with leaching tests specified by EPA.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Tests of this technology have been performed at the U.S. Bureau of Mines' Albany Metallurgy Research Center in Albany, Oregon.

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X*TRAX™ Thermal Desorption

Volatile and Semivolatile Organics and PCBs in Soil

Technology Description

The X*TRAX™ technology is a thermal desorption process designed to separate organic contaminants from soils, sludges, and other solid media. It does not involve incineration. Contaminated solids are fed into an externally heated rotary dryer where temperatures range from 750°F to 950°F. Evaporated contaminants are removed by a recirculating nitrogen carrier gas that is maintained at less than 4 percent oxygen to prevent combustion. Solids leaving the dryer are cooled with treated water to reduce dusting when the solids are returned and compacted in their original location.

The nitrogen carrier gas is treated to remove and recover dust particles, organic vapors, and water vapors. Dust particles and 10 to 30 percent of the organic contaminants are removed by an eductor scrubber. Scrubber liquid collects in a phase separator from which sludges and organic liquid phases are pumped to a filter press, producing filter cake and filtrate. The filtrate is then separated into organic liquid and water phases. Most contaminants removed from the feed solids are transferred to the organic liquids or the filter cake. The filter cake typically is blended batchwise with feed solids and reprocessed in the system, while the concentrated organic liquids are treated or disposed off site.

The gas exiting the scrubber passes through two condensers, where it is cooled to less than 40°F. The condensers separate most of the remaining water and organic vapors from the gas stream. Organic vapors are recovered as organic liquids;

water is treated by carbon adsorption and either used to cool and reduce dusting from treated solids or treated and discharged. Approximately 5 to 10 percent of the gas is cleaned by passing it through a particulate filter and a carbon adsorption system before it is discharged to the atmosphere. The volume of gas released from this process vent is approximately 100 to 200 times less than an equivalent capacity incinerator.

The system can process a wide variety of solids at feed rates up to 7.5 tons/hr. The technology is most effective for solids with a moisture content of less than 50 percent. Screening of material greater than in size than 2.25 inches may be required for some applications.

The system has been used to treat PCBs, halogenated and non-halogenated solvents, SVOCs, PAHs, pesticides, herbicides, fuel oils, BTEX, and mercury. The system also has been used to treat RCRA hazardous wastes, such as petroleum refinery wastes and multisource leachate treatment residues, to meet Land Disposal Restrictions (LDR) treatment standards.

Technology Performance

EPA conducted a SITE Program demonstration in 1992 at the Re-solve Superfund site in North Dartmouth, Massachusetts. During the demonstration, about 215 tons of soil were treated at an average feed rate of 4.9 tons/hr, a residence time of 2 hr, and an average treated soil temperature of 732°F. PCB concentrations

in contaminated soil ranged from 180 to 515 mg/kg. Key findings include:

- The system successfully removed PCBs from feed soil and met the site-specific treatment standard of 25 mg/kg for treated soils. PCB concentrations in all treated soil samples were less than 1.0 mg/kg, and the average concentration was 0.25 mg/kg. The average PCB removal efficiency was 99.9 percent.
- Polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) were not formed within the system.
- Organic air emissions from the process vent were negligible (0.4 grams/day). No PCBs were detected in the vent gases.
- The system effectively removed organic contaminants from feed soil. Concentrations of tetrachloroethene, TPHs, and oil and grease were reduced to below detectable levels in treated soil.
- Metals concentrations and soil physical properties were not altered by the system.

Remediation Costs

For most materials, the technology can process 120 to 180 tons/day at a cost ranging from \$125 to \$225/ton of feed.

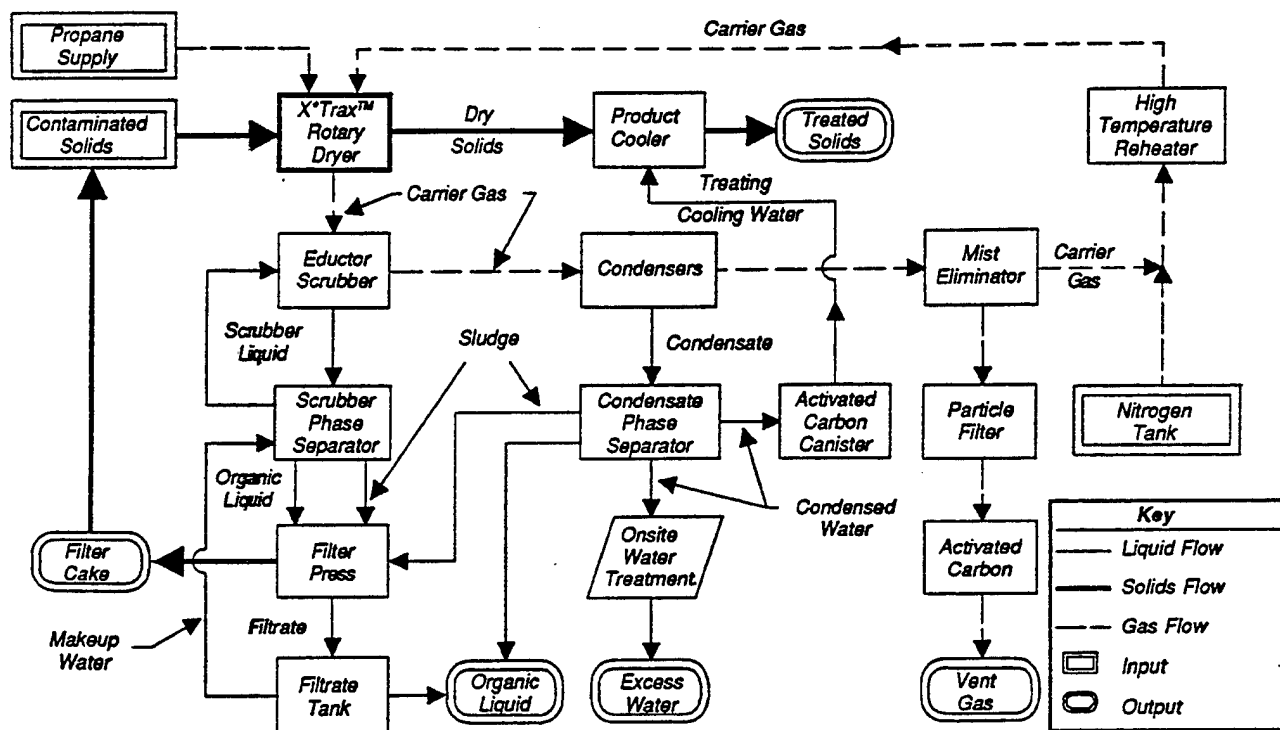
General Site Information

A full-scale demonstration under the EPA SITE Program was conducted at the Re-Solve, Inc., Superfund site in North Dartmouth, Massachusetts.

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X*TRAX™ Thermal Desorption

VAPOR EXTRACTION



Vapor Extraction

Ground Water Vapor Recovery System Volatile Organic Compounds in Ground Water (*In Situ* Treatment)

Technology Description

In this treatment, injection and extraction wells are placed outside and inside of an area of contamination. Positive pressure, from either water or air, is placed on the injection wells. Water is pumped from the extraction wells to a thermal aeration system to drive off the contaminants. Resulting vapors go to an internal combustion engine. If enough free product is available in the ground water during the cleanup process, waste hydrocarbons could be used to power the engine without the need for additional fuel.

Technology Performance

Full-scale implementation of this system began in 1991 at the Seal Beach Navy Weapons Station. This method is applicable for volatile fuels or other volatile organic compounds. This treatment requires that the contaminant be combustible. Air permits are required in some areas.

Remediation Costs

The capital cost for purchasing and installing the engine and wells is between \$70,000 and \$100,000.

General Site Information

This technology is being used at full-scale to remediate volatile fuels and other VOCs at the Seal Beach Navy Weapons Station in California.

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***In Situ* Air Stripping with Horizontal Wells**

TCE and PCE in Soil and Ground Water

Technology Description

In situ air stripping using horizontal wells is designed to concurrently remediate unsaturated-zone soils and ground water containing VOCs. The *in situ* air stripping concept utilizes two parallel horizontal wells: one below the water table and one in the unsaturated (vadose) zone. The deeper well is used as a delivery system for the air injection. VOCs are stripped from the ground water into the injected vapor phase and are removed from the subsurface by drawing a vacuum on the shallower well in the vadose zone. Horizontal wells are used because they provide more surface area for injection of reactants and extraction of contaminants and they have great utility for subsurface access under existing facilities. The technology is based on Henry's Law and the affinity of VOCs for the vapor phase. The technology is probably most effective in soils with high permeability and likely works best in sandier units with no significant aquitards between the injection and extraction wells.

In a typical demonstration of this technology, a vacuum is drawn on the shallow well for a period of two weeks, and concentration and temperature of the extracted vapors are measured at least three times a day. Air injection is then added at three different rates and at two different temperatures. Each of the operating regimes is operated for a minimum of two weeks. Helium tracer tests were also conducted to learn more about vapor flow paths and the heterogeneity of the system between the two wells. To assist with analysis and

monitoring of the demonstration, tubes of varying lengths were installed in both horizontal wells to monitor pressure and concentrations along their entire length.

Technology Performance

Almost 16,000 lbs of solvents were removed during a demonstration at the DOE Savannah River Site (SRS). Extraction rates during the vapor extraction phase averaged 110 lbs of VOCs/day. The extraction flow rate was constant at approximately 580 scfm during the entire length of the test. During the air injection periods with medium (170 scfm) and high (270 scfm) rates, approximately 130 lbs of VOCs were removed daily.

Concentrations of chlorinated solvents removed during vapor extraction decreased rapidly only during the first two days of operation. Initial concentrations were as high as 5,000 ppm but stabilized at 200 to 300 ppm. Concentrations of VOCs in the ground water were significantly reduced in several of the monitoring wells. For example, ground water from two monitoring wells showed changes from 1,600 and 1,800 µg/L TCE at the beginning of the test to 10 to 30 µg/L at the end of the 20 weeks. However, ground water in several of the wells showed no significant change and ground water in three wells actually showed increases in TCE concentrations. One possible explanation for this is that more contaminated water at depth (below the monitoring point) was being forced upward due to air injection.

The activity of indigenous microorganisms was found to increase at least an order of magnitude during the air injection periods. This activity then decreased when the air injection was terminated. It is possible that simple injection of air stimulated microorganisms that have the potential to degrade TCE. Injection of heated air appeared to have no effect on the amount of contaminant extracted from the shallow well.

Remediation Costs

The cost of the remediation demonstration project, not including site characterization was approximately \$300,000, or \$20/lb of contaminant removed. Site preparation costs, including well installation were \$300,000 to \$450,000. Equipment for this demonstration test was rented; however, purchase of the vacuum blower and compressor would be in the range of \$200,000.

General Site Information

This 20-week field demonstration project was conducted at the DOE Savannah River Site (SRS) in Aiken, South Carolina, between July and December 1990. TCE and PCE were used at SRS as metal degreasing solvents for a number of years. The *in situ* test was conducted at the SRS Integrated Demonstration Site in the M-Area, along an abandoned process sewer line that carried wastes to a seepage basin which was operated between 1958 and 1985. A ground water plume containing elevated levels of these compounds exists over an area greater than one square mile. The sewer line acted as a source of VOCs; it is known to have leaked at numerous locations along its length. Because the source of contamination was linear at this particular location within the overall plume, horizontal wells were selected as the injection/extraction system.

The Savannah River Site is located on the upper Atlantic Coastal Plain. The site is underlain by a thick wedge of unconsolidated Tertiary and Cretaceous sediments that overlay the basement, which consists of preCambrian and Paleozoic metamorphic rocks and consolidated Triassic sediments. Ground water flow at the site is controlled by hydrologic boundaries: flow at and immediately below the water table is to local tributaries, and flow in the lower aquifer is to the Savannah River or one of its major tributaries. The water table is located at approximately 135 feet. Ground water in the vicinity of the process sewer line contains elevated concentrations of TCE and PCE to depths greater than 180 feet.

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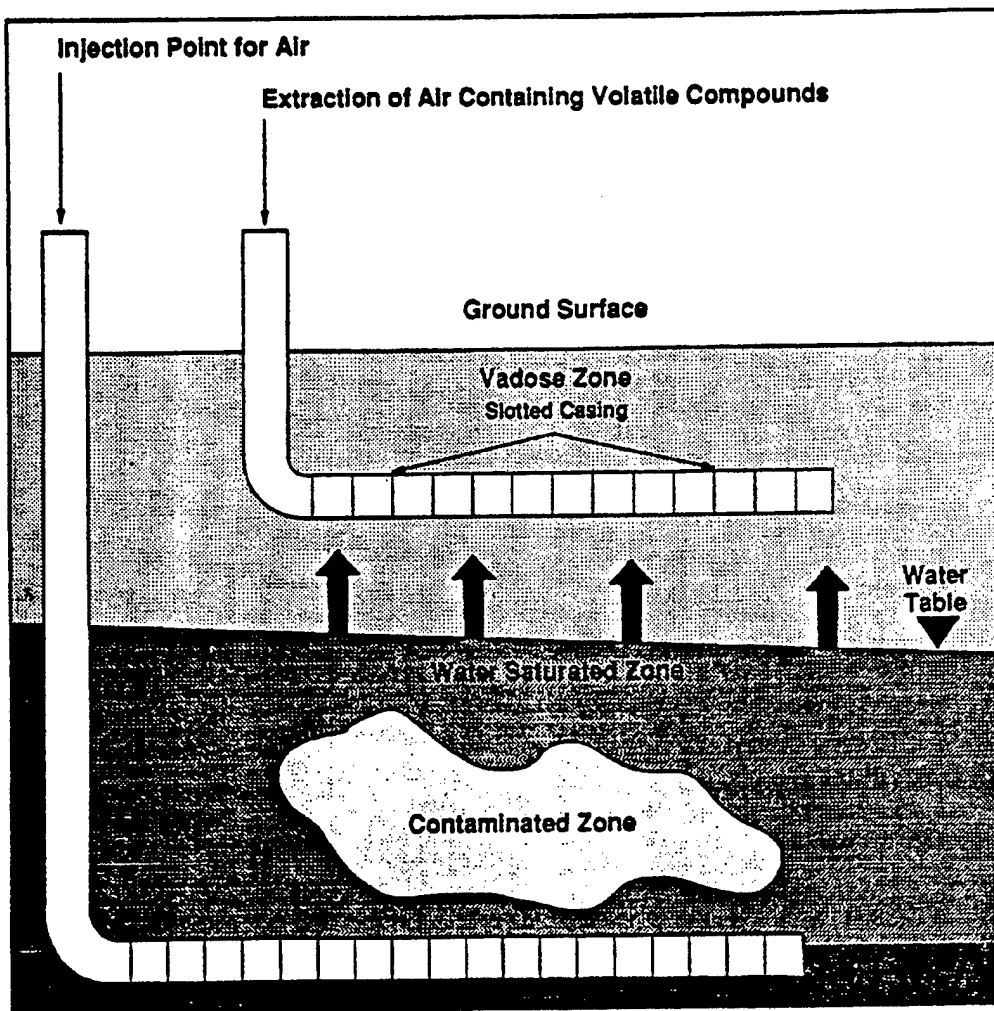


Diagram of In Situ Air Stripping with Horizontal Wells



Vapor Extraction

In Situ Soil Vapor Extraction Industrial Sludge, Waste Solvents, Fuel and Oil in Soils

Technology Description

This technology is used to treat soils contaminated with VOCs, including TCE, DCE, vinyl chloride, toluene, chlorobenzenes, and xylenes. The process is used in vadose zone soils. The technology does not work in ground water or saturated zone soils and is ineffective for removal of semivolatiles and metals.

Vadose zone extraction wells are installed at various targeted depths. A vacuum is applied and contaminants are pulled to the surface where they are treated with a catalytic oxidation unit prior to discharge to the atmosphere.

Technology Performance

A large scale pilot test involving 17 wells began in February 1993 at McClellan Air Force Base in California. Target contaminants are VOCs in the 100 to 1,000 ppm range. In addition, the Air Force is evaluating the effectiveness of enhancements such as hot air injection into the waste pit materials. Results of the demonstration and a complete evaluation of the system will be published in 1994.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The test is being conducted at a former fuel and solvent disposal site in the northwest part of McClellan Air Force Base, a Superfund site. The test area is one of 15 such sites located in Operable Unit D and contains approximately 400,000 ft³ of contaminated soil.

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***In Situ* Soil Venting**

Fuels and Trichloroethylene in Unsaturated Soils

Technology Description

The *in situ* soil venting process removes volatile contaminants such as fuels and TCE from unsaturated soils. This technology can be applied to fire training pits, spills, and the unsaturated zone beneath leach pits. The method is most applicable for contamination in fairly permeable soils.

Venting wells are placed in the unsaturated zone and connected to a manifold and blower. A vacuum is applied to the manifold, and gases are extracted from the soil and fed to the treatment system. The air flow sweeps out the soil gas, disrupting the equilibrium existing between the contaminant adsorbed on the soil and its vapor phase. This results in further volatilization of the contaminant on the soil and subsequent removal in the air stream. Depending upon the individual site and the depth of the contaminated zone, it might be necessary to seal the surface to the throughput of air.

This technology has a number of advantages. Specifically, it is inexpensive, especially if the emissions require no treatment. The equipment is easily emplaced. It is less expensive than excavation at depths greater than 40 feet. Operation is simple, excavation of contaminated soil is not required, and the site is not destroyed.

Despite the advantages of this technology, limitations do exist. This process is a transfer-of-media method; the waste is not destroyed. At depths of less than 10 feet, excavation could

be less expensive, depending upon the type of waste treatment required. The contamination must be located in the unsaturated zone above the nearest aquifer. Prior bench-scale testing is important in determining the effectiveness of the method to a specific site. To date, few field data exist on the level of cleanup. If the contamination includes toxic volatile organic carbons, then treatment of the vented gases may be required. The level of treatment is based upon local requirements.

Technology Performance

Analysis of the technology demonstration at Hill Air Force Base (AFB) in Utah have shown the following results:

- Soil gas venting may provide oxygen for biodegradation;
- Based on data from extracted gases, 80 percent of a 100,000-liter fuel spill was removed in 9 months of operation;
- Soil analysis following a full-scale *in situ* field test indicated an average fuel residual of less than 100 ppm in the soils;
- At initial air flow rates of 250 ft³/min, the full-scale system was removing 50 gpd of JP-4 from the soil. The venting rates were then increased to over 1,000 ft³/min. After 10 months of venting, over 100,000 lbs of JP-4 had been removed. Hill AFB continues to operate the system at a reduced flow rate to enhance the *in situ* biodegradation of remaining hydrocarbons; and

- Approximately 20-25 percent of the reduction in fuel hydrocarbons was caused by biodegradation.

Remediation Costs

The costs range from \$15/ton of contaminated soil, excluding emission treatment, up to approximately \$85/ton using activated carbon emission treatment. Estimated costs of this technology for sandy soils is \$10/yd³. Catalytic incineration of VOCs can double this cost. However, at Hill AFB, catalytic incineration only cost \$10/yd³.

General Site Information

Operation of a full-scale *in situ* soil-venting system at a 27,000-gallon JP-4 spill at Hill AFB, Utah, began in December 1988. A full-scale *in situ* field test was completed in October

1989. ESL TR 90-21 Vol I, *Literature Review*, Vol II, *Soil Venting Guidance Manual*, and Vol III, *Full Scale Test Results*, available from the National Technical Information Service (NTIS), document results of this effort. A cost spreadsheet is part of the design manual (Vol II) for soil venting systems and is available on request from the contact below.

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***In Situ* Soil Venting**

Volatile Contaminants in Unsaturated Soil

Technology Description

This *in situ* soil venting, or *in situ* volatilization, process removes solvents from soils without excavation. Vents (slotted pipes) are installed in the soil and a blower draws air through the vents to cause the compounds to volatilize into the air stream. At the surface the VOCs in the exhaust are dispersed directly into the air or through carbon vessels. In short, this process is based on air stripping technology.

This method is most applicable for contamination at depths greater than 40 feet in fairly permeable soils. Depending on the individual site and depth of the contaminated zone, it might be necessary to seal the surface with a clay cap to prevent channeling. This measure will also prevent any further contamination of the ground water by rainwater percolating down through the VOC-laden soils to the water table below.

Technology Performance

Prior to startup of the systems at the Twin Cities Army Ammunition Plant (TCAAP) in Minnesota, a pilot study removed 22,900 lbs of VOCs from one of the proposed sites. Continued operation of the system at this site for 7 years has removed a total of 133,623 lbs of VOCs. At a second site, the system removed 97,700 lbs of contaminants over the same time period, from early 1986 to early 1993.

Initial removal rates at the site where the pilot study was performed were 400 lbs/day of

VOCs; removal rates near the end of operation averaged 15 lbs/day. Initial removal rates at the other site were 2,000 lbs/day and decreased to a rate of 1 to 2 lbs/day later in the operation.

Downtime can be incurred when the activated carbon becomes saturated with VOCs and must be replaced. The two TCAAP soil venting systems are shut down over night and on weekends due to noise complaints from nearby residents.

Remediation Costs

The 1986 cost to construct the 40-vent system was \$212,000; the 89-vent system cost \$424,000. Costs to operate the systems at current removal rates are \$1.24/lb and \$28.85/lb, respectively. The 89-vent system removal costs are higher relative to the 40-vent system due to the following factors: (a) carbon vessels were used on the 89-vent system to control air emissions; (b) lesser quantities of VOCs were extracted by the 89-vent system; and (c) VOC removal rates for the 89-vent system have dropped significantly during recent years.

General Site Information

This method has been implemented at two separate source areas at the TCAAP. Both systems began operation in early 1986.

One area formerly contained three disposal pits that were used for the disposal of solvents, thinners, varnishes, and contaminated rags for

more than 20 years. The system at this site has 40 vents and four 20-hp blowers. The average depth of the vents is 30 feet.

The other site was a landfill area and was used as a general dump for many items, including cleaning materials, for about 30 years. The 89 vents in this system have been installed to an average depth of 40 feet, and the system uses four 40-hp blowers.

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***In Situ* Steam and Air Stripping**

Volatile and Semivolatile Organics and Hydrocarbons in Soil

Technology Description

In this technology, a transportable treatment unit Detoxifier™ is used for *in situ* steam and air stripping of volatile organics from contaminated soil.

The two main components of the on-site treatment equipment are the process tower and process train. The process tower contains two counter-rotating hollow-stem drills, each with a modified cutting bit 5 feet in diameter, capable of operating to a 27-foot depth. Each drill contains two concentric pipes. The inner pipe is used to convey steam to the rotating cutting blades. The steam is supplied by an oil-fired boiler at 450°F and 450 psig. The outer pipe conveys air at approximately 300°F and 250 psig to the rotating blades. Steam is piped to the top of the drills and injected through the cutting blades. The steam heats the ground being remediated, increasing the vapor pressure of the volatile contaminants, and thereby increasing the rate at which they can be stripped. Both the air and steam serve as carriers to convey these contaminants to the surface. A metal box, called a shroud, seals the process area above the rotating cutter blades from the outside environment, collects the volatile contaminants, and ducts them to the process train.

In the process train, the volatile contaminants and the water vapor are removed from the off-gas stream by condensation. The condensed water is separated from the contaminants by distillation, then filtered through activated carbon beds and subsequently used as make-up

water for a wet cooling tower. Steam is also used to regenerate the activated carbon beds and as the heat source for distilling the volatile contaminants from the condensed liquid stream. The recovered concentrated organic liquid can be recycled or used as a fuel in an incinerator.

This technology also is used to treat contaminated soil by injecting a wide range of reactive chemicals. Chemical injection processes include solidification/stabilization plus neutralization, oxidation, and bioremediation. The dual injection capabilities permit additional versatility. Each kelly bar can deliver two materials to the augers for injection into the soil. The injection systems replace the process train and are mounted on the same chassis that supports the technology's drilling tower.

The technology is applicable to VOCs, such as hydrocarbons and solvents, with sufficient vapor pressure in the soil. The technology is not limited by soil particle size, initial porosity, chemical concentration, or viscosity. The process is also capable of significantly reducing the concentration of semivolatile organic compounds in soil. In regard to stabilization and solidification, this technology also treats inorganics, heavy metals, and mixed wastes.

Technology Performance

An EPA SITE Program demonstration was performed in 1989 at the Annex Terminal, San Pedro, California. Twelve soil blocks were treated for VOCs and SVOCs. Various liquid samples were collected from the process during

operation, and the process operating procedures were closely monitored and recorded. Post-treatment soil samples were collected and analyzed by EPA methods 8240 and 8270. In January 1990, six blocks that had been previously treated in the saturated zone were analyzed by EPA methods 8240 and 8270. The Applications Analysis Report (EPA/540/A5-90/008) was published in 1991.

The following results were obtained during the SITE demonstration of the technology:

- More than 85 percent of the VOCs in the soil was removed;
- Up to 55 percent of SVOCs in the soil was removed;
- Fugitive air emissions from the process were very low;
- No downward migration of contaminants resulted from the soil treatment; and
- The process was timely with a treatment rate of 3 yd³/hr.

Remediation Costs

According to the EPA Applications Analysis Report, an economic analysis showed that costs range from \$252 to \$317/yd³ with on-line percentages of 70 to 90 percent.

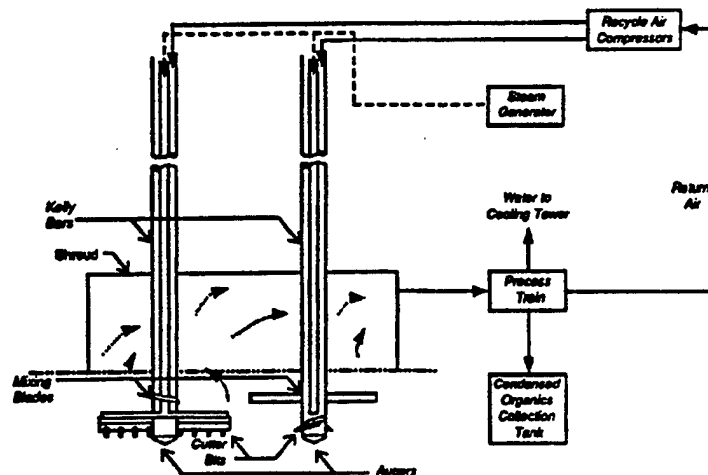
General Site Information

This technology has been demonstrated at the Annex Terminal in San Pedro, California.

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Detoxifier™ Process Schematic



Vapor Extraction

***In Situ* Steam-Enhanced Extraction (SEE) Volatile and Semivolatile Organics in Soil**

Technology Description

The *in situ* steam-enhanced extraction (SEE) process removes VOCs and SVOCs from contaminated soils both above and below the water table. Steam is forced through the soil by injection wells to thermally enhance the vapor and liquid extraction processes. Liquids are pumped from the subsurface to dewater the site. Air, steam, and organic contaminant vapors are extracted from low-pressure recovery wells. Recovered contaminants are either condensed and collected as a separate phase, processed in aqueous solution with the pumped water, or passed on to an air treatment system. After steam reaches the extraction wells and the contaminated region has reached a uniform steam temperature, steam injection continues cyclically to maintain energy levels and enhance mass transfer.

The process is used to extract VOCs and SVOCs from contaminated soils and ground water. The primary applicable compounds are hydrocarbons such as gasoline, diesel, and jet fuel, solvents such as TCE, trichloroethane (TCA), and PCE. The process may be adapted to prevent downward movement of DNAPLs. The benefits of this technology are the drastically reduced volumes of contaminated fluid to be treated on the surface, order-of-magnitude decreases in the time for remediation, applicability to liquid contaminants both above and below the water table, and potential for recycling recovered separate phase contaminants. The process can be implemented with standard boilers, fluid cooling, and separation equipment. The process cannot be

applied to contaminated soil very near the surface unless a cap exists. A license to use this patented technology can be obtained from the University of California Office of Technology Transfer (a portion of the royalty supports further University research). Site-specific design, field operation, and technical training is offered to licensed companies by Udell Technologies, Inc.

Technology Performance

In 1988, a successful pilot-scale demonstration of the process was completed at a site contaminated by a mixture of solvents. More than 750 lbs of contaminants were removed from the 10-foot-diameter, 12-foot-deep unsaturated test region.

The technology is being demonstrated under the EPA SITE Demonstration Program at a burn pit with soil contaminated by waste oil mixed with VOCs, SVOCs, and metals at McClellan Air Force Base in Sacramento, California.

A full-scale demonstration of this technology has been conducted at the Lawrence Livermore National Laboratory in Livermore, California. Gasoline is dispersed above and below the water table, and the water table depth has decreased by 25 feet since the spill occurred. The lateral distribution of second liquid phase gasoline is within a diameter of 150 feet. In the first 36 days of the demonstration, free product gasoline was recovered from the regions above and below the water table. Recovery rates were about 10 times greater than those that could be

achieved by vacuum extraction alone. The majority of the recovered gasoline came from the condenser either as a separate phase liquid or in the effluent air stream. Approximately 2,000 gal of gasoline were recovered after the first pass of steam injection.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

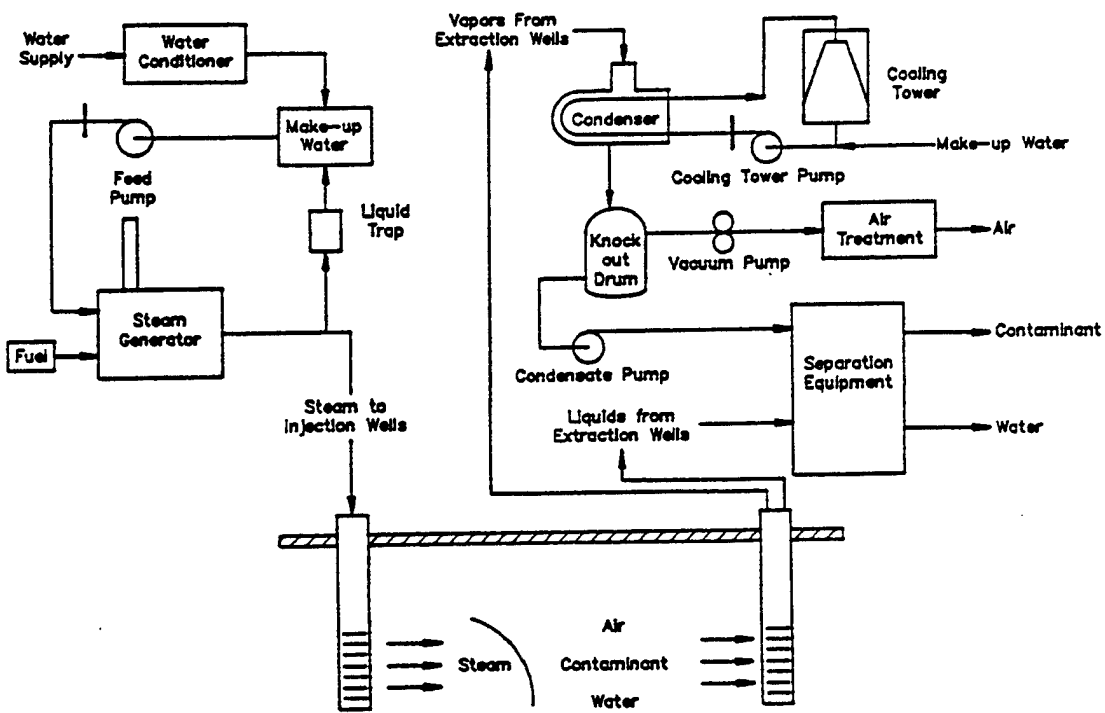
An interagency agreement between the Naval Civil Engineering Laboratory (NCEL) in Port Hueneme, California, and the EPA Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio, has been signed to enable a pilot-scale demonstration of this process at the LeMoore Naval Air Station, California. A full-scale demonstration has been conducted at DOE's Lawrence Livermore National Laboratory in Livermore, California, and the SITE Program demonstration is being conducted at McClellan Air Force Base in Sacramento, California.

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In Situ Steam Enhanced Extraction Process



***In Situ* Vacuum Extraction**

VOCs in Vadose or Unsaturated Zone Soils

Technology Description

In situ vacuum extraction is the process of removing and treating VOCs from the vadose or unsaturated zone of soils. These compounds often can be removed from the vadose zone before they contaminate ground water.

This process uses readily available equipment such as extraction and monitoring wells, manifold piping, a vapor and liquid separator, a vacuum pump, and an emission control device (such as an activated carbon filter). After the contaminated area is completely defined, extraction wells are installed and connected by piping to the vacuum extraction and treatment system.

A vacuum pump draws the subsurface contaminants from the extraction wells to the liquid/gas separator. The contaminants are then treated using an activated carbon adsorption filter or a catalytic oxidizer before the gases are discharged to the atmosphere. Subsurface vacuum and soil vapor concentrations are monitored using vadose zone monitoring wells.

The technology is effective in virtually all hydrogeological settings and can reduce soil contaminant levels from saturated conditions to non-detectable. The process works in low permeability soils (clays) with sufficient porosity. Dual vacuum extraction of ground water and vapor quickly restores ground water quality to drinking water standards. In addition, the technology is less expensive than other methods of remediation, such as incineration.

Typical contaminant recovery rates range from 20 to 2,500 lbs/day, depending on the degree of contamination at the site.

Vacuum extraction technology is effective in treating soils containing virtually all VOCs and has successfully removed more than 40 types of chemicals, including gasoline and diesel hydrocarbons.

Technology Performance

The vacuum extraction process was first demonstrated at the Superfund site in Puerto Rico, and the developer has since applied the technology at nine additional Superfund sites and at more than 400 other waste sites throughout the United States, Europe, and Japan.

The process was demonstrated under the EPA SITE Demonstration Program at Groveland Wells Superfund site in Groveland, Massachusetts, in 1987-1988. The technology successfully remediated soils contaminated with TCE. The Technology Evaluation Report (EPA/5405-89/003a) and Applications Analysis Report (EPA/540/A5-89/003) are available from EPA.

The demonstration used four extraction wells to pump contaminants to the process system. During the 56-day operational period, 1,300 lbs of VOCs, mainly TCE, were extracted from both highly permeable strata and low permeability clays. The process achieved non-detectable levels of VOCs at some locations and reduced the VOC concentrations in soil gas by

95 percent. Average reductions were 92 percent for sandy soils and 90 percent for clays. Field evaluations have yielded the following conclusions:

- VOCs can be reduced to non-detectable levels;
- Major considerations in applying this technology are volatility of the contaminants and site soils. Ideal measured permeabilities are at 10^{-4} to 10^{-8} cm/sec.
- Pilot demonstrations are necessary at sites with complex geology or contaminant distributions;
- Contaminants should have a Henry's Law constant of 0.0001 or higher.

Remediation Costs

Treatment costs are typically \$40/ton but can range from \$10 to \$150/ton, depending on requirements for gas effluent or wastewater treatment.

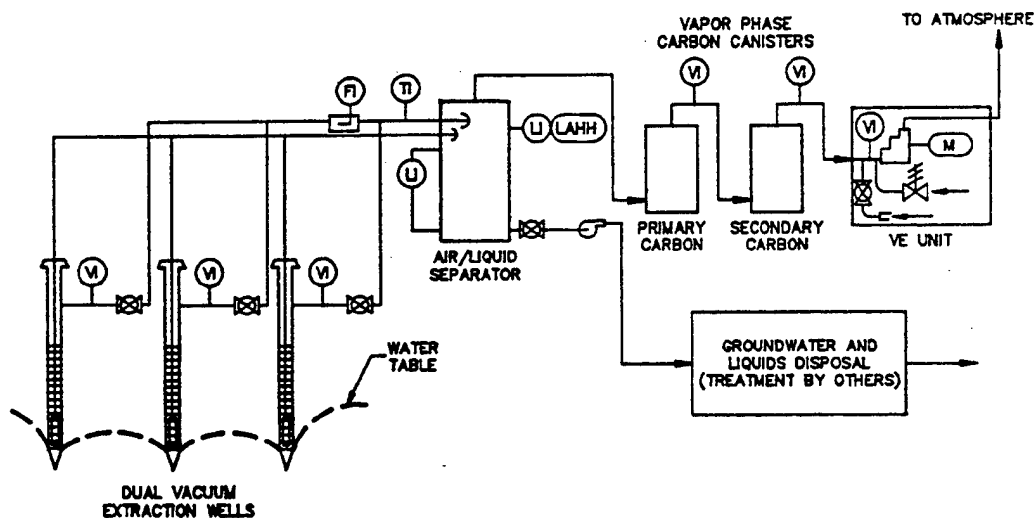
General Site Information

This process has been demonstrated at several Superfund sites, including one in Puerto Rico and one in Groveland, Massachusetts. In addition, the technology has been used extensively at sites throughout the United States, Europe, and Japan.

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In Situ Vacuum Extraction Process



Integrated Vapor Extraction and Steam Vacuum Stripping VOCs in Soil and Ground Water (*In Situ* Treatment)

Technology Description

The integrated AquaDetox/SVE system simultaneously treats ground water and soil contaminated with VOCs. The integrated system consists of two basic processes: an AquaDetox moderate vacuum stripping tower that uses low-pressure steam to treat contaminated ground water, and a soil gas vapor extraction/reinjection (SVE) process to treat contaminated soil. The two processes form a closed-loop system that provides simultaneous *in situ* remediation of contaminated ground water and soil with no air emissions.

AquaDetox is a high-efficiency, counter-current stripping technology developed by Dow Chemical Company. A single-stage unit will typically reduce up to 99.99 percent of VOCs from water. The SVE system uses a vacuum to treat a VOC-contaminated soil mass, inducing a flow of air through the soil and removing vapor phase VOCs with the extracted soil gas. The soil gas is then treated by carbon beds to remove additional VOCs and reinjected into the ground. The AquaDetox and SVE systems share a granulated activated carbon (GAC) unit. Non-condensable vapor from the AquaDetox system is combined with the vapor from the SVE compressor and is decontaminated by the GAC unit. By-products of the system are a free-phase recyclable product and treated water. Mineral regenerable carbon will require disposal after approximately three years.

A key component of the closed-loop system is a vent header unit designed to collect the non-condensable gases extracted from the ground

water or air that may leak into the portion of the process operating below atmospheric pressure. Further, the steam used to regenerate the carbon beds is condensed and treated in the AquaDetox system.

This technology removes VOCs, including chlorinated hydrocarbons, in ground water and soil. Sites with contaminated ground water and soils containing TCE, PCE, and other VOCs are suitable for this on-site treatment process.

Technology Performance

The AquaDetox/SVE system is currently being used at the Lockheed Aeronautical Systems Company in Burbank, California. The system is treating ground water contaminated with as much as 2,200 ppb TCE and 11,000 ppb PCE, and soil gas with a total VOC concentration of 6,000 ppm. Contaminated ground water is being treated at a rate of up to 1,200 gpm while soil gas is removed and treated at a rate of 300 ft³/min. The system occupies approximately 4,000 ft². It has been operating for more than three years—operating 95 percent of the time, with 5 percent downtime for scheduled or non-scheduled repairs.

An EPA SITE Program demonstration project was evaluated as part of the ongoing remediation effort at the San Fernando Valley Groundwater Basin Superfund site in Burbank, California. Demonstration testing was conducted in 1990. The Applications Analysis Report (EPA/540/A5-91/002) was published in 1991.

Key results from the demonstration include the following:

- The technology successfully treated ground water and soil gas contaminated with VOCs;
- Efficiencies were in the 99.92 to 99.99 percent range for removal of VOCs from contaminated ground water. VOC removal efficiencies for soil gas ranged from 98.0 to 99.9 percent when the GAC beds were regenerated according to SWD-specified frequency (8-hr shifts). VOC removal efficiencies dropped to as low as 93.4 percent when the GAC beds were regenerated less frequently;
- The technology produced effluent ground water that complied with regulatory discharge requirements for TCE and PCE (5 µ/L for each compound);
- The GAC beds effectively removed VOCs from contaminated soil gas even after 24 hrs of continuous operation without steam regeneration; and
- Steam consumption dropped with decreasing tower pressures. The system was more efficient at lower operating tower pressures.

Remediation Costs

The system is estimated to cost approximately \$3.2, \$4.3, and \$5.8 million for the 500-, 1,000-, and 3,000-gpm systems, respectively, with total annual operation and maintenance costs of about \$410,000, \$630,000, and \$1,500,000, respectively.

General Site Information

This technology was demonstrated at the San Fernando Valley Groundwater Basin Superfund site in Burbank, California. It also is being used to treat groundwater at the Lockheed Aeronautical Systems Company in Burbank.

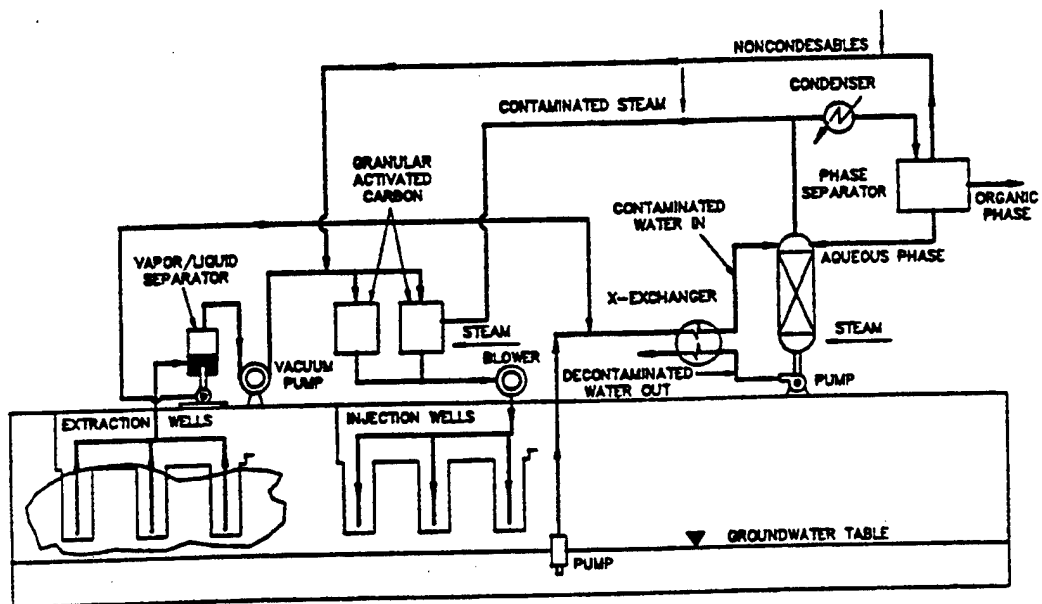
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Integrated Vapor Extraction and Steam Vacuum Stripping



Soil Vapor Extraction (SVE) JP-4 Jet Fuel in Soil (*In Situ* Treatment)

Technology Description

This technology consists of a system of air extraction wells installed throughout the contaminated soils. The wells are connected to a blower system capable of extracting air through the soil matrix. Volatile compounds present in the soil gas and adsorbed on the soils are volatilized and withdrawn from the soil. Soil vapor extraction also can be used to enhance biological processes in the soil to treat semivolatiles or non-volatiles by increasing the oxygen content of the soil gas.

The SVE system may consist of one or more 4-inch PVC inlet and/or air extraction wells. The anticipated depth of the wells will be about 60 feet. The system can be skid-mounted and located away from the impacted area. It includes a blower with muffler, air/water separator, vacuum relief valve, and gauges. Sample ports and direct reading instrumentation also can be included. Air emissions can be treated by a thermal treatment unit or granular activated carbon (GAC). Volatile compounds in the blower discharge will be treated before discharging to the atmosphere. If GAC is selected, the spent carbon and liquid wastes resulting from condensation of soil moisture in the SVE system are then disposed of at a permitted treatment facility.

Technology Performance

Full-scale remediation of the North Fire Training Area at Luke Air Force Base in Glendale, Arizona, was conducted in 1992. The

SVE system used consisted of two 60-foot extraction wells operating at 100 scfm. Target contaminants are benzene at 16 ppm, ethylbenzene at 84 ppm, toluene at 183 ppm, xylene at 336 ppm, and TRPH at 1,380 ppm. Soil borings and soil gas samples were used to evaluate effectiveness of the treatment. Residual condensate was collected from extraction well piping at a rate of 8 gpd and incinerated.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The remediation involves 35,000 yd³ of contaminated soil at the North Fire Training Area. Currently not in use, the area had been the scene of fire training exercises using JP-4 jet fuel since 1973.

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Vapor Extraction

Steam-Enhanced Recovery Process (SERP) Volatile and Semivolatile Organics in Soils (*In Situ* Treatment)

Technology Description

This process removes most VOCs and SVOCs from contaminated soils in situ above and below the water table. The technology is applicable to the in situ remediation of contaminated soils below ground surface and can be used to treat below or around permanent structures. The process accelerates contaminant removal rates and can be effective in all soil types. Steam is forced through the soil by injection wells to thermally enhance the recovery process. Extraction wells are used to pump and treat ground water and to transport steams and vaporized contaminants to the surface. Recovered nonaqueous liquids are separated by gravity separation. Hydrocarbons are collected for recycling, and water is treated before being discharged to the storm drain or sewer. Vapors can be condensed and treated by any of several vapor treatment techniques—for example, thermal oxidation or catalytic oxidation. The technology uses readily available components such as extraction and monitoring wells, manifold piping, vapor and liquid separators, vacuum pumps, and gas emission control equipment.

The process can be used to extract VOCs and SVOCs from contaminated soils and perched ground water. Compounds suitable for treatment are hydrocarbons, solvents, or mixtures of these compounds. After application of the process, subsurface conditions are excellent for biodegradation of residual contaminants. The process cannot be applied to contaminated soil very near the ground surface unless a cap exists. Denser-than-water

compounds can be treated only in low concentrations unless a geologic barrier exists to prevent downward percolation.

Technology Performance

The EPA SITE demonstration of this technology was completed in early 1993 at Huntington Beach, California. The soil site was contaminated by a large diesel fuel spill.

Remediation Costs

Cost information was not provided for this publication.

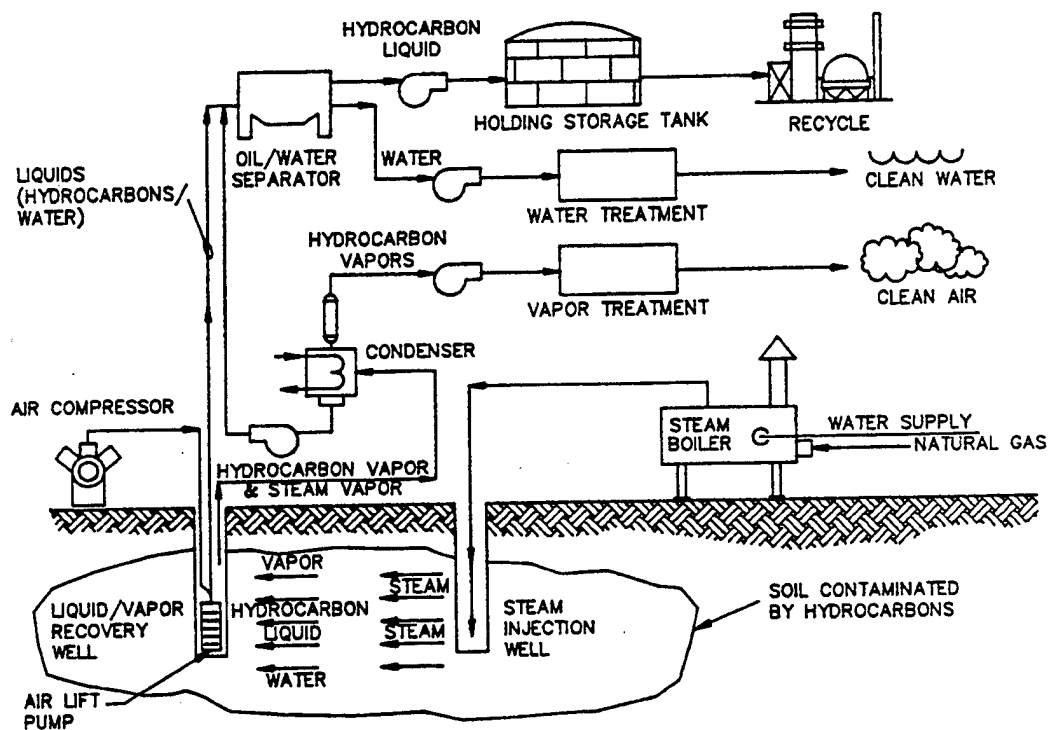
General Site Information

This technology was demonstrated at a diesel fuel spill site in Huntington Beach, California.

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Steam Enhanced Recovery Process



Subsurface Volatilization and Ventilation System (SVVS) Organics in Soil (*In Situ* Treatment)

Technology Description

The SVVS uses a network of injection and extraction wells (collectively, a reactor nest) to treat subsurface organic contaminants via soil vacuum extraction combined with *in situ* biodegradation. Each system is custom-designed to meet site-specific conditions. A series of injection and extraction wells is installed at a site. The number and spacing of the wells depends on the results of applying a design parameters matrix and modeling, as well as physical, chemical, and biological characteristics. One or more vacuum pumps create negative pressure to extract contaminated vapors, while an air compressor simultaneously creates positive pressure across the site. Control is maintained at a Vapor Control Unit that houses pumps, control valves, gauges, and other control mechanisms. At most underground storage tank (UST) sites, the extraction wells are placed above the water table and the injection wells are placed below the ground water. The exact depth of the injection wells and screen interval are additional design considerations.

To enhance vaporization, solar panels are occasionally used to heat the injected air. Additional valves for limiting or increasing the air flow and pressure are placed on individual reactor nest lines (radials) or, at some sites, on individual well points. Depending on ground water depths and fluctuation, horizontal vacuum screens, "stubbed screens," or multiple-depth completions can be applied. The system is dynamic: positive and negative air flow can be shifted to different locations on site to place the

most remediation stress on the areas requiring it. Negative pressure is maintained at a suitable level to prevent escape of vapors.

Because it provides oxygen to the subsurface, the SVVS can enhance *in situ* biodegradation at a site, the technology, unlike most air sparging systems, is designed and operated to enhance bioremediation, so it can decrease project life significantly. These processes are normally monitored by checking dissolved oxygen levels in the aquifer, recording carbon dioxide in lines and at the emission point, and periodically sampling microbial populations. If air quality permits require it, VOC emissions can be treated by a biological filter (patent-pending) that uses indigenous microbes from the site.

The developer is focusing on increasing the microbiological effectiveness of the system and completing the testing of a mobile unit. The mobile unit will allow field pilot tests to support the design process. This unit also will permit actual remediation of small sites and of small, recalcitrant areas on large sites.

The technology is applicable to sites with leaks or spills of gasoline, diesel fuels, and other hydrocarbons. The system is very effective on BTEX contamination. It also can be used to contain contaminant plumes through its unique vacuum and air injection techniques. The technology should be effective in treating soils contaminated with virtually any material that has some volatility or is biodegradable. The technology can be applied to contaminated soil, sludges, free-phase hydrocarbon product, and ground water. By changing the injected gases

to cause anaerobic conditions and properly supporting the microbial populations, the SVVS can be used to remove nitrate from ground water. The aerobic SVVS raises the redox potential of ground water, to precipitate and remove heavy metals.

Technology Performance

The SVVS has been used at 30 UST sites in New Mexico and Texas. This technology was accepted into the EPA SITE Demonstration Program in 1991. A site in Buchanan, Michigan, was selected for a demonstration which began in 1992 and will be completed in 1993.

Remediation Costs

Cost information was not provided for this publication.

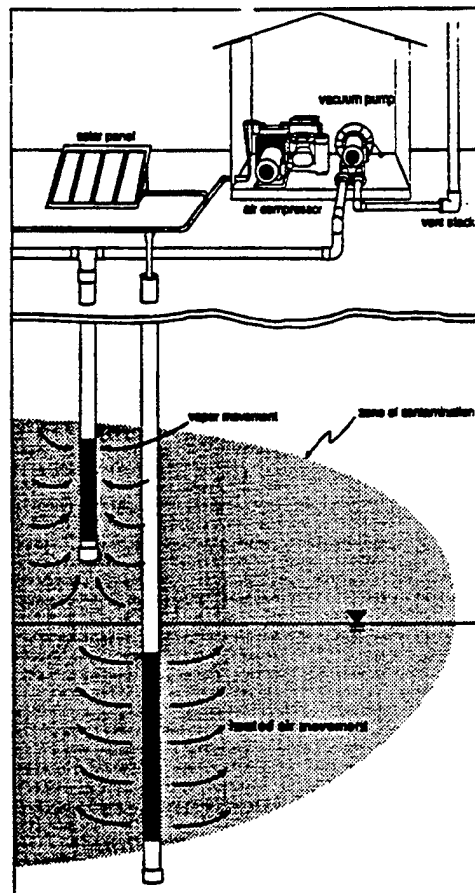
General Site Information

A SITE Program demonstration is ongoing at a site in Buchanan, Michigan.

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Subsurface Volatilization and Ventilation System (SVVS)



Vacuum-Induced Soil Venting Gasoline in Unsaturated Soil (*In Situ* Treatment)

Technology Description

The vacuum-induced venting process provides *in situ* cleanup of gasoline contamination above and below the water table. It reduces contamination to levels low enough to eliminate further leaching or desorption of gasoline into the ground water. This technology can be applied to hydrocarbon fuels in unsaturated soil.

A vapor/ground-water extraction well, and a well for monitoring the vacuum induced venting are installed in the gas spill area. The vapor extraction/monitor wells each have five individually screened intervals in the unsaturated zone and two screened intervals below the water table. A vacuum-extraction system with thermal oxidizer is installed using one well to remediate the spill area. The vacuum-extraction system operates with a vacuum of between 20-25 inches of mercury and with a flow rate of approximately 60 ft³/min. The present system uses an open pipe at the top of an air-driven pump, which is manually adjusted to follow the gasoline water interface. Both wells are used for skimming gasoline.

Technology Performance

Results from testing the vacuum-induced soil venting technology at the DOE's Lawrence Livermore National Laboratory (LLNL) were positive:

- Approximately 100 gallons of free product were removed with this system;

- Approximately 5,000 gallons of gasoline were removed via vacuum-induced venting over a 12-month period;
- Over the 12-month period, total fuel hydrocarbon concentrations (measured at the inlet of the thermal oxidizer), decreased from 16,000 ppm to about 3,000-4,000 ppm; and
- The thermal oxidizer that destroys the gaseous hydrocarbons as they are removed operated with a 99.8 percent destruction efficiency.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Prior to 1979, approximately 17,000 gallons of regular gasoline leaked into the soil and ground water from an underground fuel storage tank at the DOE's Lawrence Livermore National Laboratory. Vacuum-induced venting was demonstrated at this site as a method to clean the gasoline contamination *in situ*.

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Vapor Extraction

Vapor Extraction System Solvents in Soil (*In Situ* Treatment)

Technology Description

This technology uses a vacuum pump/blower to treat vadose zone soils contaminated with VOCs. The increased airflow in the vadose zone resulting from use of the vapor extraction system also assists in the biodegradation of other organics.

Vapor, extracted using the process, is treated using a thermal burner or catalytic oxidation prior to being discharged to the atmosphere. Entrained contaminated water, if any, is transported off site to a permitted facility for treatment.

Technology Performance

Full-scale remediation of a site at the Sacramento Army Depot in California was conducted late in 1992 and early in 1993. Target contaminants were ethylbenzene, butanone, xylene and PCE.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The remediation involves about 200 yd³ of soil in the Tank 2 area of the Sacramento Army Depot in California. Contamination in the area was found to a depth of 18 feet, with the majority between 9 and 18 feet. The contaminated area currently is covered with a slab. The tank has been removed.

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SOIL WASHING



BEST™ Solvent Extraction Process

PCBs, PAHs, and Pesticides in Oily Sludges and Soil

Technology Description

Solvent extraction treats oily sludges and soils contaminated with PCBs, PAHs, and pesticides by separating the sludges into three fractions: oil, water, and solids. As the fractions separate, contaminants are partitioned into each fraction. For example, PCBs are concentrated in the oil fraction, while metals are separated into the solids fraction. The volume and toxicity of the original waste is thereby reduced, and concentrated waste streams can be efficiently treated for disposal.

The BEST™ process is a mobile solvent extraction system that uses one or more secondary or tertiary amines (usually triethylamine [TEA]) to separate organics from soils and sludges. TEA is hydrophobic above 20 °C and hydrophilic below 20°C. This property allows the process to extract both aqueous and nonaqueous compounds by simply changing the temperature.

Because TEA is flammable in the presence of oxygen, the treatment system must be sealed from the atmosphere and operated under a nitrogen blanket. Before treatment, the pH of the waste material must be raised to greater than 10, so that TEA will be conserved for recycling through the process. The pH may be adjusted by adding sodium hydroxide. Pretreatment also includes screening the waste to remove large particles.

The process begins by mixing and agitating the cold solvent and waste in a cold extraction tank. Solids from the cold extraction tank are transferred to the extractor/dryer, a horizontal steam-

jacketed vessel with rotating paddles. Hydrocarbons and water in the waste simultaneously solubilize with the TEA, creating a homogeneous mixture. As the solvent breaks the oil-water-solid emulsions in the waste, the solids are released and allowed to settle by gravity. The solvent mixture is decanted and centrifuged to remove fine particles. After extraction, the treated solids are kept moist to prevent dusting.

The solvent mixture from the extractor/dryer is heated. As the mixture's temperature increases, the water separates from the organics and solvent. The organics-solvent fraction is decanted and sent to a stripping column, where the solvent is recycled. The organics are discharged for recycling or disposal. The water is passed to a second stripping column where residual solvent is recovered for recycling. The water is typically discharged to a local wastewater treatment plant.

The technology is modular, allowing for on-site treatment. Based on bench-scale treatability tests, the process significantly reduces the hydrocarbon concentration in the solids. It also concentrates the contaminants into a smaller volume, allowing for the efficient final treatment and disposal. Other advantages of the technology include the production of dry solids, and recovery and reuse of soil.

The process can be used to remove most hydrocarbons or oily contaminants in sediments, sludges, or soils, including PCBs, PAHs and pesticides (see next page). Performance can be influenced by the presence of detergents and

emulsifiers, low pH materials, and reactivity of the organics with the solvent.

SPECIFIC WASTES CAPABLE OF TREATMENT BY SOLVENT EXTRACTION

RCRA-Listed Hazardous Wastes

- Creosote-Saturated Sludge
- Dissolved Air Flotation (DAF) Float
- Slop Oil Emulsion Solids
- Heat Exchanger Bundle Cleaning Sludge
- API Separator Sludge
- Leaded Tank Bottoms

Non-Listed Hazardous Wastes

- Primary Oil/Solids/Water Separation Sludges
- Secondary Oil/Solids/Water Separation Sludges
- Bio-Sludges
- Cooling Tower Sludges
- HF Alkylation Sludges
- Waste FCC Catalyst
- Spent Catalyst
- Stretford Unit Solution
- Tank Bottoms
- Treated Clays

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1987. The SITE demonstration of the BEST™ process was completed in 1992 at the Grand Calumet River. Results of the demonstration are documented in an EPA Applications Analysis Report (EPA/540/AR-92/079). The first full-scale BEST™ unit was used at the General Refining Superfund site in Garden City, Georgia. Solvent extraction is the selected remedial action at the Ewan Property site in New Jersey, the Norwood PCB site in Massachusetts, and the Alcoa site in Massena, New York. It is also the preferred alternative at the F. O'Connor site in Maine.

Remediation Costs

Based on the SITE demonstration, cost for a 186-ton/day system have been estimated at \$94.19/ton treated. This excludes mobilization and demobilization, estimated at \$680,000; equipment checkout, estimated at \$56,000; site

preparation, estimated at \$100,000; and other fixed costs, estimated at \$91,500.

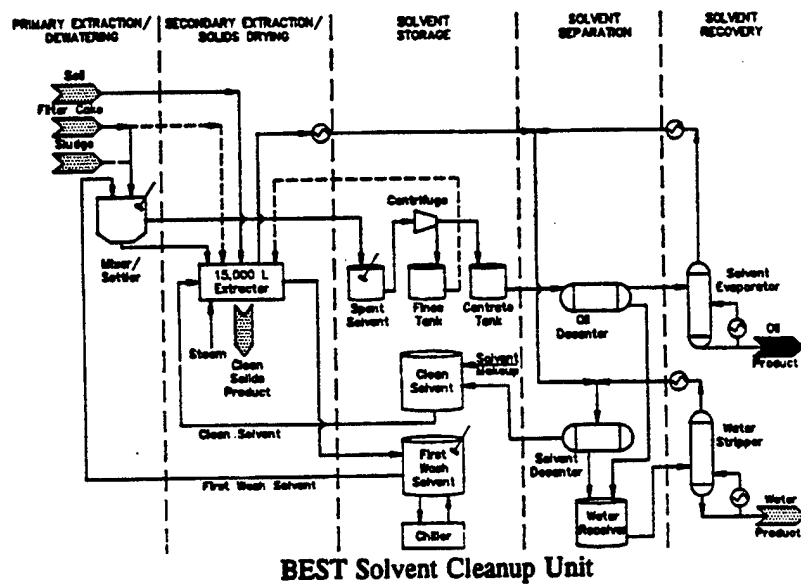
General Site Information

This technology has been demonstrated at the Grand Calumet River site in Illinois, and a full-scale unit was used at the General Refining Superfund site in Garden City, Georgia.

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BioGenesisSM Soil Washing Process

Volatile and Non-Volatile Hydrocarbons and PCBs in Soil

Technology Description

The BioGenesisSM process uses a specialized truck, a complex surfactant, and water to clean soil contaminated with organics. Ancillary equipment includes gravity oil and water separators, coalescing filters, and a bioreactor. All equipment is mobile, and treatment normally occurs on site. The cleaning rate for oil contamination of 5,000 ppm is 30-65 tons/hr. A single wash removes 85 to 99 percent of hydrocarbon contamination, up to 15,000 ppm. Higher concentrations require additional washes.

Up to 65 tons (35 yd³) of contaminated soil are loaded into a washer unit containing water and BioGenesisSM cleaner. The BioGenesisSM cleaner is a light alkaline mixture of natural and organic materials containing no hazardous or petrochemical ingredients. For 15 to 30 minutes, aeration equipment agitates the mixture, washing the soil, and encapsulating oil molecules with BioGenesisSM cleaner. After washing, the extracted oil is reclaimed, wash water is recycled or treated, and the soil is dumped from the soil washer. Hazardous organics, such as PCBs, can be extracted in the same manner and then processed by using compound-specific treatment methods.

Advantages of BioGenesisSM include (1) treatment of soils containing both volatile and non-volatile oils, (2) treatment of soil containing up to 50 percent clays, (3) high processing rates, (4) on-site operation, (5) production of reusable oil, treatable water, and soil suitable for on-site backfill, (6) the absence of air pollution, except

during excavation, (7) and accelerated biodegradation of oil residuals in the soil.

This technology extracts volatile and non-volatile oils, chlorinated hydrocarbons, pesticides, and other organics from most types of soils, including clays. Treatable contaminants include crude oil, heating oils, diesel fuel, gasoline, PCBs, and PAHs.

Technology Performance

The BioGenesisSM technology was accepted into the EPA SITE Demonstration Program in June 1990. The process was demonstrated at Santa Maria, California, in May 1992 and at a mid-west refinery in November 1992. Full commercial operations began in Wisconsin in September 1992.

Research continues to extend application of the technology to acid extractables, base and neutral extractables, pesticides, and acutely hazardous materials.

Remediation Costs

BioGenesisSM soil washing technology costs \$40 to \$150/ton depending on five major factors:

- type of contaminant—Residual oils require more cleaning time and chemical than does diesel. The presence of hazardous components, such as benzene or PCBs, adds the safety costs associated with hazardous waste processing;

- quantity of contaminant—Very high levels, such as 30,000 to 60,000 ppm, may require multiple washes depending on the cleaning standard;
- cleanup goal—Achieving 100 ppm residuals costs more than achieving 1,000 ppm;
- soil type—Sandy soil costs less to clean than soil with high clay content; and
- job size—On a per-ton basis, production efficiency is higher and costs are lower for larger jobs.

These cost ranges include moving soil from a stockpile, washing it, and returning it to the stockpile. They also include internal quality assurance testing, but do not include testing for outside entities.

General Site Information

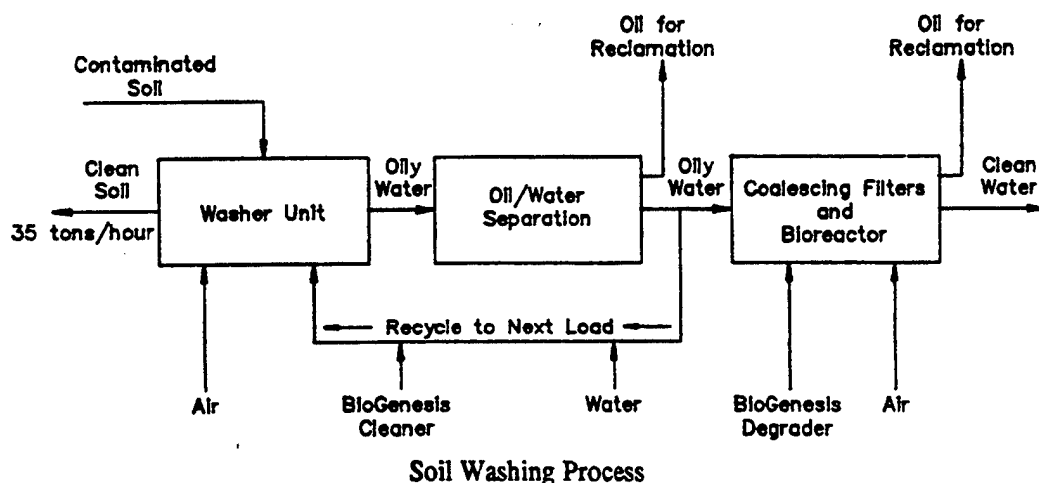
This technology was demonstrated at a site in Santa Maria, California, and at a midwest refinery site.

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Carver-Greenfield Process

Oil-Soluble Organics in Soils, Sediments, and Sludges

Technology Description

The Carver-Greenfield (C-G) Process® is a solvent extraction process designed to separate hazardous oil-soluble organic contaminants from sludges, soils, and sediments. The process involves adding to the waste a "carrier" oil, which removes hazardous organics from contaminated solid particles and concentrates them in the oil phase. In most applications, a food-grade oil with a boiling point of 400°F is used as the carrier oil. Typically, 5 to 10 lbs of carrier oil is used for each pound of solids. First, carrier oil is added to the waste in a mixing tank. The mixture is then transferred to a high-efficiency evaporator where the water is removed. Next, the dry mixture is fed to a centrifuge that separates the oil from the solid particles. Additional solvent extractions and centrifuging take place at this point. After final centrifuging, any residual carrier oil is removed by hydro-extraction, a de-oiling process that uses hot nitrogen gas to separate oil from solids. The final solids product typically contains low percentages of water and oil. In the full-scale system, recirculated oil is distilled to recover carrier oil, which is subsequently reused.

By-products from the process include: (1) a concentrated mixture of the extracted oil-soluble compounds, (2) a water product virtually free of solids and oils, and (3) a clean, dry solid.

The C-G Process can be applied to wastes containing water and organic contaminants. Commercial C-G Process plants have been used to treat materials with high water content, such as meat rendering waste, municipal sewage

sludge, paper mill sludge, brewery treatment plant sludge, pharmaceutical plant waste, and leather dyeing waste. The system cannot process large particles. If necessary, waste feed should be pretreated using a grinder to a maximum particle size of about 1/4 inch. The process can treat wastes with oil-soluble contents ranging from ppm levels up to 75 percent. Because the process is based on a dewatering technology, it can treat waste streams containing up to 99 percent water.

Technology Performance

The process was demonstrated in 1991 on drilling muds excavated from the PAB Oil Superfund site in Abbeville, Louisiana. The demonstration was conducted at EPA's research facility in Edison, New Jersey. A trailer-mounted C-G unit treated about 640 lbs of drilling mud wastes in two separate test runs.

Operation of the system:

- generated a treated solids product that passed TCLP criteria for volatiles, semivolatiles, and metals;
- successfully separated the feed stream into its constituent water, oil, and solids fractions;
- removed 94 to 96 percent of the indigenous oil and 100% of the indigenous TPH from the solid fraction (see on next page); and

- produced a dry final solids product containing less than 1 percent carrier oil.

Demonstration results have been published by EPA in an Applications Analysis Report (EPA/540/AR-92/002). The report also is available from NTIS (PB93-101152).

Remediation Costs

Based on remediating 23,000 tons of spent drilling fluids, C-G Process technology specific costs would be typically in the range of \$100 to 220/ton of drilling mud waste feed and would be expected to be comparable for similar feeds. Site-specific costs, which include the cost of residual disposal, range from minimal (<\$10/ton) to more than \$300/ton of drilling mud waste feed and are very sensitive to the assumed residuals disposition and associated costs or credits. Costs to treat other materials could be in the range of \$50 to \$100/ton.

General Site Information

This technology was demonstrated at EPA's Edison, New Jersey, facility using waste from the PAB Oil Superfund site in Abbeville, Louisiana.

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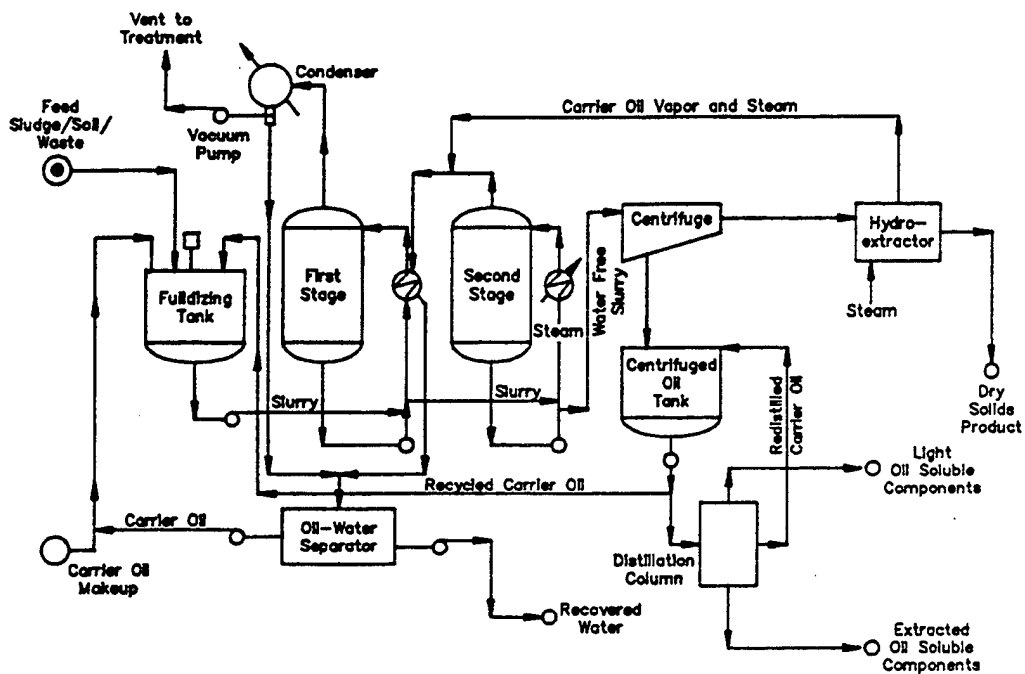
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Demonstration Results

Parameter	Test Run #1		Test Run #2	
	Feed, %	Solids Product, %	Feed, %	Solids Product, %
Solids	52.4	96.6	52.4	98.3
Indigenous Oil	17.5	1.45	7.28	0.85
Water	21.8	N/D ¹	34.7	N/D ¹
Carrier Oil	N/D ¹	0.93	N/D ¹	0.89
Percent Indigenous Oil Removal ²	95.9		94.3	
Percent Indigenous TPH Removal	100		100	

¹ N/D: Not Detected

² Percent removal is based on the solids fraction of the influent feed.



Carver-Greenfield Process® Schematic Diagram



Debris Washing System

Organics, PCBs, Pesticides, and Inorganics in Debris

Technology Description

This technology was developed to decontaminate debris currently found at Superfund sites. The pilot-scale debris washing system (DWS) includes 300-gallon spray and wash tanks, surfactant and rinse water holding tanks, and an oil-water separator. The DWS uses a diatomaceous earth filter, an activated carbon column, and an ion exchange column to treat the decontamination solution. Other required equipment includes pumps, a stirrer motor, a tank heater, a metal debris basket, and particulate filters.

The DWS unit is transported on a 48-foot semitrailer. At the treatment site, the DWS unit is assembled on a 25-by-24-foot concrete pad and enclosed in a temporary shelter.

A basket of debris is placed in the spray tank with a forklift, where it is sprayed with an aqueous detergent solution. High-pressure water jets blast contaminants and dirt from the debris. Detergent solution is continually cleaned and recycled through a filter system.

The spray and wash tanks are supplied with water at 140°F, at a pressure of 60 lbs/psig. The detergent solution and rinse water are treated by oil-water separation, particulate filtration, activated carbon adsorption, and ion exchange. About 1,000 gallons of liquid are used during the decontamination process.

The DWS can be applied on site to various types of debris (metallic, masonry, or other solid

debris) contaminated with hazardous chemicals, such as pesticides, PCBs, lead, and other metals.

Technology Performance

The first pilot-scale test was performed at Carter Industrial Superfund site in Detroit, Michigan. PCB reductions averaged 58 percent in Batch 1 and 81 percent in Batch 2. Design changes were made and tested on the unit before additional field testing.

An upgraded pilot-scale DWS at the PCB-contaminated Gray Superfund site in Hopkinsville, Kentucky, during December 1989. PCB levels on the surfaces of metallic transformer casings were reduced to less than or equal to 10 µg/100 cm² PCBs. All 75 contaminated transformer casings on site were decontaminated to EPA cleanup criteria and sold to a scrap metal dealer.

The DWS was also field tested at the Shaver's Farm Superfund site in Walker County, Georgia. The contaminants of concern were benzonitrile and dicamba. After being cut into sections, 55-gallon drums were placed in the DWS and carried through the decontamination process. Benzonitrile and dicamba levels on drum surfaces were reduced from the average pretreatment concentrations of 4,556 and 23 µg/100 cm² to average concentrations of 10 and 1 µg/100 cm², respectively. Results have been published in a Technology Evaluation Report (EPA/540/5-91/006a).

A full-scale version of the DWS has been designed and is available for demonstration. This system is similar to the pilot-scale system; however, the equipment, which will be mounted on two 48-foot semi-trailers, has been scaled up to permit processing of 10 to 20 tons/day.

Remediation Costs

The cost for design, engineering, equipment procurement, fabrication, and installation of the pilot-scale DWS was approximately \$75,000. The cost of conducting each demonstration—site preparation, mobilization, equipment set-up, operations/test runs, sample collections, chemical analyses, and demobilization—was \$122,000 for the Gray PCB site and \$140,000 for the Shaver's Farm site. These costs may not be representative of any actual site operation because of the experimental nature of the pilot-scale system which is relatively labor intensive and has a low processing rate.

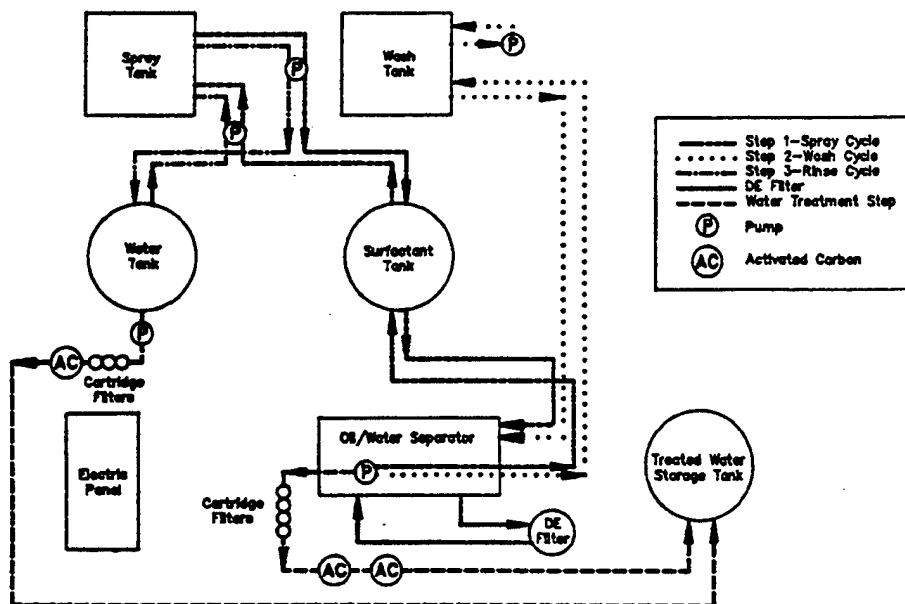
General Site Information

Demonstrations and field tests of this technology have been conducted at the Carter Industrial Superfund site in Detroit, Michigan, a Superfund site in Hopkinsville, Kentucky, and the Shaver's Farm Superfund site in Walker County, Georgia.

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Pilot-Scale Debris Washing System



Enhanced Soil Washing with SOIL*EX™ Radionuclides and Heavy Metals in Soil and Debris

Technology Description

This technology is designed for selective extraction of heavy metals and radionuclides from soil and debris. Specific contaminants addressed by the technology include plutonium, americium, uranium, radium, lead, chromium, and organics such as TCE and CCl₄.

Pretreatment, consisting of manual segregation of sheets of plastic, pieces of deteriorated and broken drums, and large shards of metal, is required. This is followed by size separation of soil/debris to particles smaller than 2 inches.

The treatment portion of the process involves selective dissolution of the contaminants, combined with the use of surfactants to remove organic materials. This is followed by solid/liquid separation, with a side-stream to a waste concentration unit, and volatile organic destruction using the evaporation-plus-catalytic-oxidation technology, PO*WW*ER™. (See the Chemical Treatment section for a description of the PO*WW*ER™ technology.)

The process produces four outlet streams: clean soil/debris, concentrated contaminants, condensed water for re-use in the cycle, and air discharge of carbon dioxide and nitrogen from the oxidized organic compounds.

Technology Performance

Bench-scale tests of soils with plutonium and uranium have been conducted showing effective and selective removal of contaminants with

varying degrees of decontamination factors (DFs). A pilot-scale plant is being constructed, and pilot-scale treatability studies, with bench-scale support, are being conducted at the Clemson Technical Center in Anderson, SC.

Remediation Costs

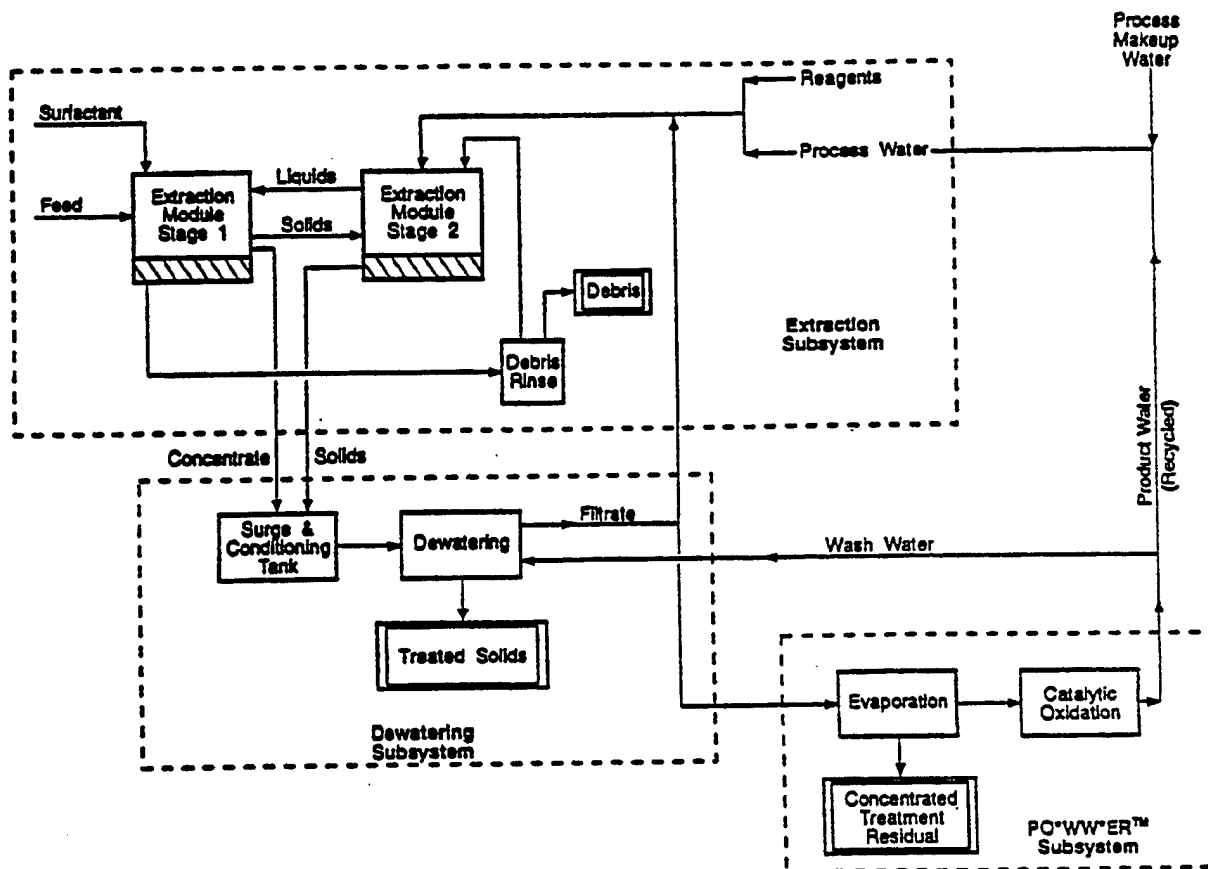
Cost information was not provided for this publication.

General Site Information

Clemson Technical Center is a facility licensed and permitted to handle radioactive and hazardous materials and was developed as a site for demonstration of technologies treating mixed, radioactive, and hazardous wastes.

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Enhanced Soil Washing Process Flow Diagram



Soil Washing

Particle Separation Process PCBs and Metals in Sediments

Technology Description

This technology separates contaminated particles by density and grain size. The technology operates on the hypothesis that most contamination is concentrated in the fine particle fraction (-63 micron fines), and that contamination of larger particles generally is not extensive.

In this technology, contaminated soil is screened to remove coarse rock and debris. Water and chemical additives (such as surfactants, acids, bases, and chelants) are added to the soil to produce a slurry feed. The slurry feed flows to an attrition scrubbing machine. Rotary trommel screws, dense media separators, and other equipment create mechanical and fluid shear stress, removing contaminated silts and clay from granular soil particles. Different separation processes then create output streams consisting of granular soil particles, silts, clays, and wash water.

Upflow classification and separation, also known as elutriation, is used to separate light contaminated specific gravity materials, such as leaves, twigs, roots, or wood chips.

This technology is suitable for treating sediment contaminated with PCBs. The technology has been applied to soils and sediments contaminated with organics and heavy metals, including cadmium, chromium, lead, creosote, copper, cyanides, fuel residues, mercury, heavy petroleum, nickel, PCBs, radionuclides, and zinc.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in winter 1991. A pilot-scale, on-site demonstration was conducted from October 1991 to June 1992 at the U.S. Army Corps of Engineers' Saginaw Bay Confined Disposal Facility in Bay City, Michigan. The demonstration was part of the Assessment and Remediation of Contaminated Sediments (ARCS) Program authorized by the Water Quality Act of 1987. Approximately 30 yd³ of sediments dredged from the Saginaw River was treated each day during the demonstration. Contaminants and grain size were monitored at 23 points in the process.

The process also was field evaluated in Toronto, Ontario, Canada, in April 1992.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Demonstrations and evaluations of this technology have been conducted at the U.S. Army Corps of Engineers' Saginaw Bay Confined Disposal Facility in Bay City, Michigan, and at a site in Toronto, Ontario, Canada.

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RENEU™ Extraction Technology

Organics in Soil

Technology Description

This RENEU™ Extraction Technology is a mobile system that removes organic compounds from soil. Concentrations can be reduced from as high as 325,000 ppm to non-detectable, depending on the soil and contaminants. The system can handle sand, clay, and soil aggregates up to 3 inches in diameter. Processing treatment rates range from 5 to over 45 tons/hr.

The technology uses a proprietary, azeotropic fluid that works in both the liquid and gas phase. The fluid physically breaks the adsorption bond between the contaminant and the soil under ambient conditions. Upon contact with the fluid, contaminants are released from the solid surface and form a colloidal suspension. The fluid/organic contaminant emulsion is centrifuged. The contaminants are then extracted from the fluid through a liquefaction/distillation process. The fluid can be formulated to have a boiling point from 80° to 120°F. All fluid and contaminant vapors are collected and routed to the liquification/distillation unit. The extracted fluid can be reused.

The system does not require significant pretreatment or processing water. Application equipment consists of a Transportable Treatment Unit (TTU), a centrifuge, and a Gas Liquefaction and Distillation Unit (GLDU). The TTU consists of the hopper and auger processor coupled with the RENEU™ storage and delivery system and is mounted on one trailer. The second trailer carries the centrifuge, GLDU, and, when needed, a generator to power both. The centrifuge spins the dampened soil. The GLDU collects

the liquid and gaseous contaminants captured in the fluid, then separates the fluid from the contaminants by distillation.

A skip loader transports the contaminated soil into the hopper of the TTU, which feeds the soil directly into the treatment chamber. Contaminated soil is screened and broken up in the hopper before it proceeds to the auger.

In the treatment chamber, several pressure spray heads apply the fluid directly onto the contaminated soil. Residence time is varied by feed rate, which depends on contaminant and soil conditions.

Four vacuum hoses on top of the auger housing create a slight negative pressure. Volatilized material is captured and liquefied in the GLDU.

The treated soil is conveyed from the auger outlet into the centrifuge, where it receives an optional final rinse of fluid. After centrifuging, the soil is routed to a holding area prior to sampling and backfilling.

The system extracts organic compounds including gasoline, diesel, jet fuels, waste oils, oil processing sludges, and various other hydrocarbon-based contaminants in most types of soils, including clays. Additional applications are being investigated.

Technology Performance

The technology was accepted into the EPA SITE Demonstration Program in June 1992. A demonstration was conducted in 1992.

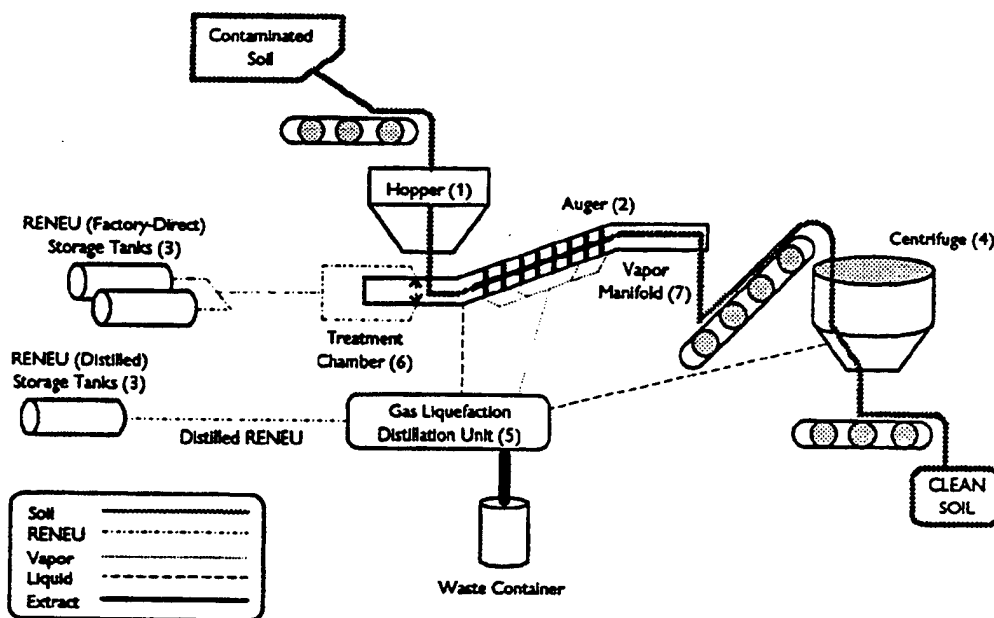
Remediation Costs

Cost information was not provided for this publication.

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Reneu™ Extraction System



Soil Washing

Soil Restoration Unit PCBs, PCP, Creosote, Chlorinated Solvents, Naphthalene, Diesel Oil, Used Motor Oil, Jet Fuel, Grease, and Organic Pesticides in Soil

Technology Description

The soil restoration unit is a mobile solvent extraction device designed to remove organic contaminants from soil. Extraction of soil contaminants is performed with a mixture of organic solvents in a closed loop, counter-current process that recycles all solvents. The technology uses a combination of up to 14 solvents, each of which can dissolve specific contaminants in the soil and mixes freely with water. None of the solvents is a listed hazardous waste, and the most commonly used solvents are approved by the Food and Drug Administration as food additives for human consumption. The solvents are typically heated to efficiently strip the contaminants from the soil.

Contaminated soil is fed into a hopper, and then mixed to form a slurry. Soil in the slurry is continually leached by clean solvent. The return leachate from the modules is monitored for contaminants so that the soil may be retained within the system until any residual contaminants within the soil are reduced to targeted levels. The soil restoration unit offers "hot spot protection," in which real-time monitoring of the contaminant levels alleviates the problems associated with treating localized areas of higher contamination.

Used solvent from the slurry modules is stripped of contaminants by distillation. Materials extracted from the soil remain in distillation residuals and are periodically flushed from the system into 55-gal. drums for off-site disposal.

distillate from the columns is fractionally separated to remove the lower boiling point contaminants from the solvent. The clean solvent is then reused in the system, completing the closed solvent loop.

Treated soil and solvent slurry is then sent to a closed-loop dryer system that removes the solvent from the soil. The solvent vapors in the dryer are monitored with an organic vapor monitor that indicates when the treatment has been completed.

This technology is can remove PCBs, PCP, creosote, chlorinated solvents, naphthalene, diesel oil, used motor oil, jet fuel, grease, organic pesticides, and other organic contaminants in soil. It has not been tested using contaminated sediments and sludges as feed stock.

Technology Performance

The soil restoration unit has been used for remediation of the Traband Warehouse site in Oklahoma. Results from that site are shown below:

<u>Test</u>	<u>Initial PCBs Conc. (ppm)</u>	<u>Final PCBs Conc. (ppm)</u>	<u>Required No. of Passes</u>	<u>Percent Reduction</u>
A	740	77	1	90
B	810	3	1	99+
C	2,500	93	4	96

Remediation Costs

Cost information was not provided for this publication.

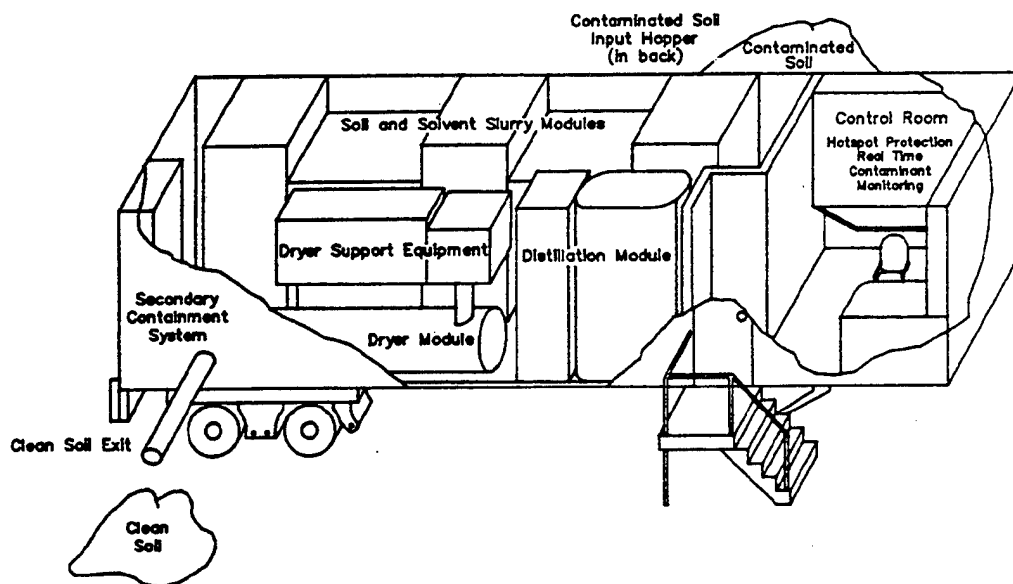
General Site Information

This technology was used for PCB remediation at Traband Warehouse in Oklahoma. An Emergency Response action, cleanup of the site has been completed.

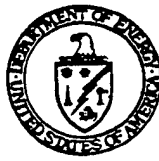
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Soil Restoration Unit



Soil Washing

Soil Washer for Radioactive Soil Radionuclides in Soils

Technology Description

This technology is designed to reduce the volume of soils contaminated with low concentrations of radionuclides. The process is used with soils in which radioactivity is concentrated in the fine soil particles and in friable coatings around the larger particles.

The soil washer uses attrition mills to liberate the contaminated coatings and then uses hydro-classifiers to separate the contaminated fines and coatings. Next, a filter press dewater the contaminated portion in preparation for off-site disposal. The clean portion remains on site, reducing the high costs of transporting and burying large volumes of low-level radioactive soil.

Technology Performance

The soil washer was tested with soil from the Montclair Superfund site in New Jersey. The result was a 56 percent volume reduction of 40 picoCuries/gram soil, with the clean portion at 11 picoCuries/gram. The soil washer also achieved steady-state operations for 8 hours, with little operator assistance, at the rate of approximately 1 ton/hr. The plant is now being optimized in preparation for the second round of testing.

This process was developed as part of EPA's Volume Reduction/Chemical Extraction (VORCE) Program which also involves laboratory screening and bench-scale testing of soils for active Department of Energy sites. These

include the Nevada Test Site, Hanford Reservation, Idaho National Engineering Laboratory, Rocky Flats, the Fernald Plant, and two other New Jersey sites that are part of DOE's Formerly Utilized Site Remedial Action Program (FUSRAP).

Remediation Costs

Disposal and transportation cost is being negotiated. Based on the first round of testing of the pilot soil washing plant, volume reduction at a rate of about 1.5 yd³/hr has an operational cost of about \$300/hr.

General Site Information

This technology is being developed for the Montclair and the West Orange and Glen Ridge Superfund sites, both in New Jersey.

Contact

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Soil Washing

Soil Washing Metals in Oxidation Lagoons

Technology Description

In this process, soil is treated with a wash reagent that facilitates the transfer of contaminants, primarily heavy metals and arsenic, from the soil to the wash liquid. The wash liquid then will be neutralized with a caustic to precipitate the metals from the solution. The precipitated metals will be disposed of in a landfill.

Technology Performance

Full-scale remediation of 12,000 yds³ of soil at the Sacramento (California) Army Depot was conducted in 1992. The soil had been found to be contaminated to a depth of 18 inches. Primary contaminants were cadmium, nickel, lead, and copper.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This remediation project involves a group of four contaminated oxidation lagoons at the Sacramento Army Depot in California. The lagoons currently are not in use and are covered partially with vegetation. Three drainage ditches and a dry section of a nearby creek also have been contaminated from spillover from the lagoons following rainstorms.

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Soil Washing

Soil Washing Uranium in Soil

Technology Description

In this process, a mixture of soil and leachant is attrition scrubbed for one minute to solubilize the uranium from the soil. The contents of the attrition scrubber then flow into the mineral jig where the fine uranium particles and contaminated solutions are separated from the soil. The contaminated materials overflow from the jig, while clean soils exit from the bottom. The bottom soils are then screened and washed to remove any uranium residuals. The fines slurry from the jig is treated to remove organic materials, then flocced and removed from process using a rotary screen and classifier. The leachant is reactivated and recycled.

Wastewater effluent is a by-product of this process. Effluent must be analyzed for hazardous constituents. Existing wastewater treatment technologies should allow the wastewater to be treated and returned to a useable water source.

Technology Performance

This technology is commercially available and has been used in the field. It is being evaluated at DOE's Fernald Site, near Cincinnati, Ohio, as part of its Integrated Technology Demonstration program for Uranium Soils.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The Fernald Site is located on 1,050 acres near the Great Miami River, 18 miles northwest of Cincinnati, OH. Established in the early 1950s, the production complex was used for processing uranium and its compounds from natural uranium ore concentrates. As the primary production site for uranium metal for defense projects in the past, the facility was key to national security.

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Soil Washing/Catalytic Ozone Oxidation SVOCs, PCBs, PCP, Pesticides, Dioxin, and Cyanide in Soil, Sludge, and Ground Water

Technology Description

The Excalibur technology is designed to treat soils with organic and inorganic contaminants. The technology is a two-stage process: the first stage extracts the contaminants from the soil, and the second stage oxidizes contaminants present in the extract. The extraction is carried out using ultra-pure water and ultrasound. Oxidation involves the use of ozone, and ultraviolet light. The treatment products of this technology are decontaminated soil and inert salts.

After excavation, contaminated soil is passed through a 1-inch screen. Soil particles retained on the screen are crushed using a hammermill and sent back to the screen. Soil particles passing through the screen are sent to a soil washer, where ultra-pure water extracts the contaminants from the screened soil. Ultrasound acts as a catalyst to enhance soil washing. Typically, 10 volumes of water are added per volume of soil, generating a slurry of about 10 to 20 percent solids by weight. This slurry is conveyed to a solid/liquid separator, such as a centrifuge or cyclone, to separate the decontaminated soil from the contaminated water. The decontaminated soil can be returned to its original location or disposed of appropriately.

After the solid/liquid separation, any oil present in the contaminated water is recovered using an oil/water separator. The contaminated water is ozonated prior to oil/water separation to aid in oil recovery. The water then flows through a filter to remove any fine particles. After the

particles are filtered, the water flows through a carbon filter and a deionizer to reduce the contaminant load on the multichamber reactor. In the multi-chamber reactor, ozone gas, ultraviolet light, and ultrasound are applied to the contaminated water. Ultraviolet light and ultrasound catalyze the oxidation of contaminants by ozone. The treated water (ultrapure water) flows out of the reactor to a storage tank and is reused to wash another batch of soil. If makeup water is required, additional ultrapure water is generated on site by treating tap water with ozone and ultrasound.

The treatment system is also equipped with a carbon filter to treat the off-gas from the reactor. The carbon filters are biologically activated to regenerate the spent carbon.

System capacities range from 1 ft³/hr of solids (water flow rate of 1 gpm) to 27 yd³/hr of solids (with a water flow rate of 50 gpm). The treatment units available for the EPA SITE Program demonstration can treat 1 to 5 yd³/hr of solids.

This technology can be applied to soils, solids, sludges, leachates, and ground water containing organics such as PCBs, PCP, pesticides and herbicides, dioxins, and inorganics, including cyanides. The technology could effectively treat total contaminant concentrations ranging from 1 ppm to 20,000 ppm. Soils and solids greater than 1 inch in diameter need to be crushed prior to treatment.

Technology Performance

The Excalibur technology was accepted into the EPA SITE Demonstration Program in July 1989. The Coleman-Evans site in Jacksonville, Florida, has been selected for a SITE demonstration.

Remediation Costs

Depending upon the level of contaminants and type of soils, costs range from \$70 to \$130/yd³ with no need for landfilling, incineration, or chemical treatment.

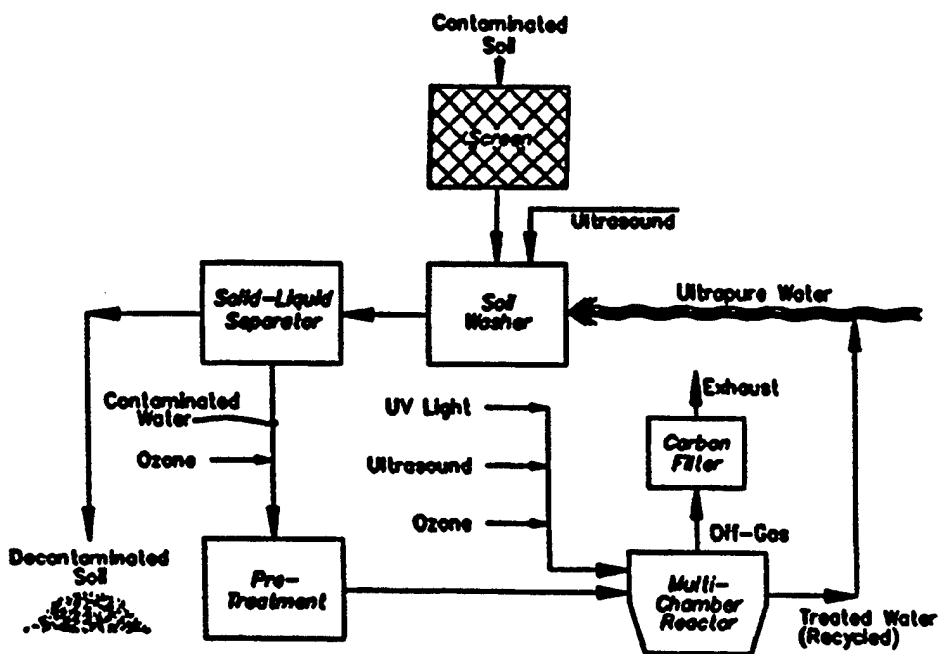
General Site Information

This technology is expected to be demonstrated at the Coleman-Evans site in Jacksonville, Florida.

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Excalibur Treatment System Flow Diagram



Soil Washing Plant Radionuclides and Heavy Metals in Soil

Technology Description

The Soil Washing Plant is a highly portable, cost-effective, above ground process for reducing the overall volume of contaminated soil requiring treatment.

The demonstration plant is contained on an 8-foot-by-40-foot trailer and transported with a pickup truck. The processing rate depends on the percentage of soil fines in the feed material. During the EPA SITE Program demonstration, the system processed between 2.5 and 5 tons/hr of contaminated soil; however, the unit can operate at up to 20 tons/hr. The system uses conventional mineral processing equipment for deagglomeration, density separation, and material sizing, centered around a patented process for effective fine particle separation. By use of high attrition and wash water, soil contaminants are partitioned to fine soil fractions. Oversized coarse soil fractions are washed in clean water before exiting the plant for redeposition on site. Process water is containerized, recirculated, and treated to remove suspended and dissolved contaminants. Fine contaminated soil fractions are containerized automatically during plant operation.

The system can be up-scaled. A 150-ton/hour plant, built in 1989 for mining gold, processed 47,000 yds³ (71,400 tons) of material.

The technology can be used to treat soil contaminated with radioactive and heavy metals. Metals concentration will not influence system throughput. Currently the developer is design-

ing a plant that employs soil washing for remediation of hydrocarbon-contaminated soil.

The technology recirculates all process water and containerizes the entire waste stream; the only non-containerized products leaving the plant are washed, clean coarse soil fractions. Its complete containment of the waste stream makes the system an environmentally responsible approach to soil remediation.

Technology Performance

The Soil Washing Plant was accepted into the EPA SITE Demonstration Program in winter 1991. Under the Program, the system was demonstrated in the late summer 1992 for the remediation of lead-contaminated soil at the Alaska Battery Enterprises (ABE) Superfund site in Fairbanks, Alaska.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology was demonstrated at the Alaska Battery Enterprises (ABE) Superfund site in Fairbanks, Alaska. The ABE site was added to the National Priorities List because of high levels of lead found in site soils and the potential for ground water contamination. The lead contamination resulted from past manufacturing

and recycling of batteries at the site. EPA removed some contaminated soil from the site in 1988 and 1989. Further site testing in 1990 revealed that additional contaminated soil remained on site. This technology was selected primarily because the site soil gravel and sand, with a minimum of clay and silt. These soil characteristics make the site highly amenable to this soil washing system. Analysis of the excavated soil revealed large quantities of metallic lead and contaminated battery casings; the developer quickly modified its process to separate these additional contaminants.

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Soil Washing System

PAHs, PCBs, PCP, Pesticides, and Metals in Soil

Technology Description

This soil washing system is a patented, water-based, volume reduction process for treating excavated soil. Soil washing may be applied to contaminants concentrated in the fine-size fraction of soil (silt, clay, and soil organic matter) and the mainly surficial contamination associated with the coarse (sand and gravel) soil fraction. The goal is for the soil product to meet appropriate cleanup standards.

After debris is removed, soil is mixed with water and subjected to various unit operations common to the mineral processing industry. Process steps can include mixing trommels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering operations.

The core of the process is a multi-stage, counter-current, intensive scrubbing circuit with inter-stage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated fine particles from the coarser sand and gravel. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized, as dictated by solubility characteristics or partition coefficients.

The contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Options for the contaminated fines

include off-site disposal, incineration, stabilization, and biological treatment.

This technology was initially developed to clean soils contaminated with wood preserving wastes such as PAHs and PCP. The technology may also be applied to soils contaminated with petroleum hydrocarbons, pesticides, PCBs, various industrial chemicals, and metals.

Technology Performance

The EPA SITE demonstration of the soil washing technology took place in 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. A pilot-scale unit with a treatment capacity of 500 lbs/hr was operated 24 hrs/day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 130 ppm PCP and 247 ppm total PAHs. During the second phase (7 days), soil containing 680 ppm PCP and 404 ppm total PAHs was fed to the system.

Contaminated process water from soil washing was treated biologically in a fixed-film reactor and was recycled. A portion of the contaminated fines generated during soil washing was treated biologically in a three-stage, pilot-scale EIMCO Biolift® reactor system supplied by the EIMCO Process Equipment Company.

Following is a summary of the results of the demonstration of this technology:

- Feed soil (dry weight basis) was successfully separated into 83 percent washed soil, 10

percent woody residues, and 7 percent fines. The washed soil retained about 10 percent of the feed soil contamination; while 90 percent of the feed soil contamination was contained within the woody residues, fines and process wastes.

- The soil washer achieved up to 89 percent removal of PCP and 88 percent of total PAHs, based on the difference between ppm levels in the contaminated (wet) feed soil and the washed soil.
- The system degraded up to 94 percent of PCP in the process water from soil washing. PAH removal could not be determined due to low influent concentrations.

The Applications Analysis Report (EPA/540/A5-91/003) is available from EPA.

Remediation Costs

Cost of a commercial-scale soil washing system, assuming use of all three technologies, was estimated to be \$168/ton. Incineration of woody material accounts for 76 percent of the cost.

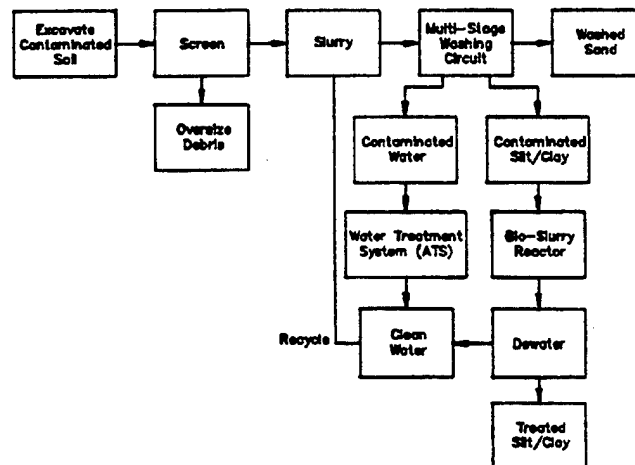
General Site Information

This technology was demonstrated at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota.

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BioTrol Soil Washing System Process Diagram



Soil Washing

Solvent Extraction PCBs, VOCs, SVOCs, and Petroleum Wastes in Soil and Sludge

Technology Description

This technology uses liquified gases as solvent to extract organics from sludges, contaminated soils, and wastewater. Propane is the solvent typically used for sludges and contaminated soils, while carbon dioxide is used for wastewater streams. The system is available as either a continuous flow unit for pumpable wastes or a batch system for non-pumpable soils and sludges.

Contaminated solids, slurries, or wastewaters are fed into the extractor along with solvent. Typically, more than 99 percent of the organics are extracted from the feed. Following phase separation of the solvent and organics, the mixture of solvent and organics passes from the treated feed to the solvent recovery system. Once in the solvent recovery system, the solvent is vaporized and recycled as fresh solvent. The organics are drawn off and either reused or disposed of. Treated feed is discharged from the extractor as a slurry in water.

The extractor design is different for contaminated wastewaters and semisolids. A tray tower contactor is used for wastewaters, and a series of extractor/decanter are used for solids and semisolids.

This technology can be applied to soils and sludges containing VOCs and SVOCs and other higher boiling complex organics, such as PAHs, PCBs, dioxins, and PCP. This process can treat refinery wastes and organically contaminated wastewater.

Technology Performance

Under the EPA SITE Program, a mobile demonstration unit (MDU) was tested on PCB-laden sediments from the New Bedford (Massachusetts) Harbor Superfund site during September 1988. PCB concentrations in the harbor sediment ranged from 300 ppm to 2,500 ppm. The Technology Evaluation Report (EPA/540/5-90/002) and the Applications Analysis Report (EPA/540/A5-90/002) were published in August 1990.

CF Systems Corporation completed the first commercial on-site treatment operation at Star Enterprise, in Port Arthur, Texas. The propane-based solvent extraction unit processed listed refinery K- and F-wastes, producing treated solids that met EPA land-ban requirements. The unit operated continually from March 1991 to March 1992, with an on-line availability in excess of 90 percent. Following fixation for heavy metals, the treated solids were disposed of in a Class I landfill.

During operation, 100 percent of the feed material treated met land-ban specifications. Multiple feeds, including API separator solids, slop oil emulsion solids, slop oils, and contaminated soils, were treated.

This technology has been selected by EPA Region 6 and Texas Water Commission on a "sole source" basis for clean up of the 80,000 cubic yard United Creosoting site at Conroe, Texas. This Superfund site is heavily contaminated with wood treatment wastes.

Other on-going demonstrations and applications of this technology include an on-site pilot demonstration at the O'Connor Superfund site in Augusta, Maine for Central Maine Power. This site is heavily contaminated with PCBs and has a cleanup standard of 1 ppm.

This technology was demonstrated concurrently with dredging studies managed by the U.S. Army Corps of Engineers. Contaminated sediments were treated by the CF Systems Pit Clean-up Unit, using a liquified propane and butane mixture as the extraction solvent. Extraction efficiencies were high, despite some operating difficulties during the tests. Development of full-scale commercial systems, including batch extractors, eliminated problems with the pilot plant at the New Bedford site. The field evaluation yielded the following results:

- Extraction efficiencies of 90 to 98 percent were achieved on sediments containing between 360 and 2,575 ppm PCBs. PCB concentrations were as low as 8 ppm in the treated sediment.
- In the laboratory, extraction efficiencies of 99.9 percent have been obtained for volatile and semivolatile organics in aqueous and semisolid wastes.
- Operating problems included solids retention in the system hardware and foaming in receiving tanks. Successful corrective measures were implemented in the full-scale commercial units.

Remediation Costs

Projected costs for PCB cleanups are estimated at approximately \$150 to \$450/ton, including material handling and pre- and post-treatment costs. These costs are highly sensitive to the utilization factor and job size, which may result in lower costs for large cleanups.

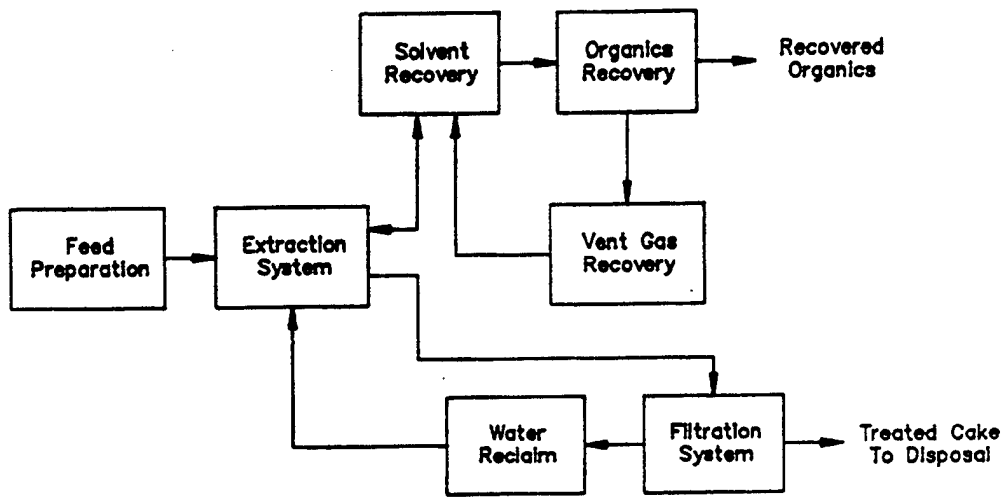
General Site Information

This technology has been demonstrated at the New Bedford Harbor Superfund site in New Bedford, Massachusetts, and the O'Connor site in Augusta, Maine. It has been used commercially at the Star Enterprise site in Port Arthur, Texas, and has been selected for cleanup of the United Creosoting site in Conroe, Texas.

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Solvent Extraction Remediation Process



Soil Washing

Volume Reduction Unit **Volatile and Semivolatile Organics and Metals in Soils**

Technology Description

The Volume Reduction Unit (VRU) is a pilot-scale, mobile soil washing system designed to remove organic contaminants from soil through particle separation and solubilization. The VRU can process 100 lbs/hr (dry weight).

The process subsystems include soil handling and conveying, soil washing and coarse screening, fine particle separation, flocculation/clarification, water treatment, and utilities. The VRU is controlled and monitored with conventional industrial process instrumentation and hardware.

The VRU can treat soils that contain organics such as creosote, PCP, pesticides, PAHs, VOCs, SVOCs, and metals.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in summer 1992. The demonstration was conducted in November 1992 at a wood preserving site in Pensacola, Florida.

Remediation Costs

Cost information was not provided for this publication.

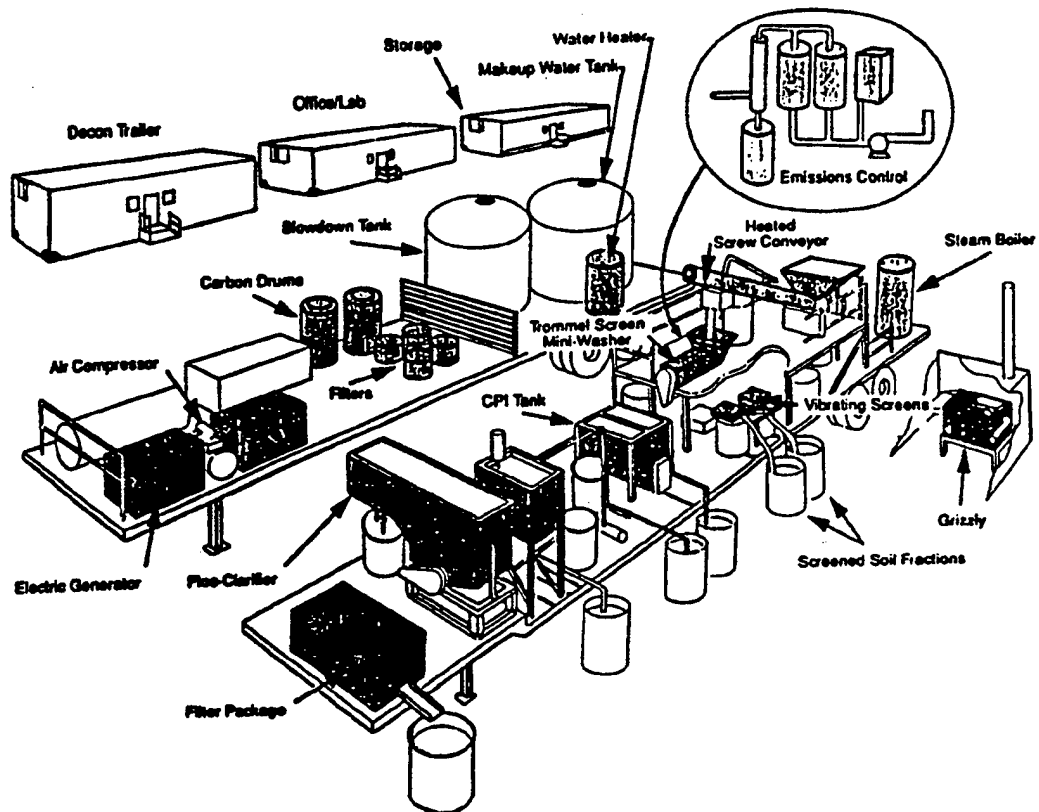
General Site Information

This technology was demonstrated at a wood preserving site in Pensacola, Florida.

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Volume Reduction Unit

OTHER PHYSICAL TREATMENT



Advanced Oxidation Process VOCs in Ground Water

Technology Description

This technology uses the oxidative power of the advanced oxidation processes (AOPs) to destroy ordnance contaminants in ground water. The AOPs involve using ultraviolet (UV) radiation, hydrogen peroxide, and ozone in various combinations to produce hydroxyl radicals to destroy the target organics. Although UV, hydrogen peroxide, and ozone have oxidative power individually, the primary oxidative power in the AOP reactions are from the hydroxyl radicals.

Laboratory studies both in formal laboratory setting and in commercial vendor shops were conducted to determine the capabilities of the AOP reactions available currently to destroy low-level ordnance contaminants in ground water. The treatment goals were to reach treatment criteria for ordnance compounds specified in Washington State regulations. Laboratory findings indicated that the best AOP option is UV/ozone which can treat the ground water to meet specified treatment criteria: 2.9 µg/L for TNT and 0.8 µg/L for RDX. Because the oxidation of ordnance compounds can result in production of more toxic by-products, studies are being conducted to avoid undesirable results.

The organics targeted in this effort are TNT and RDX, the most frequently found and persistent components of ordnance contamination. Contamination is the result of past ordnance-related disposal practices. As these organics are not readily soluble, their concentrations in contaminated ground water are typically low. However, their presence in the drinking water supply aquifer

presents a health threat and is closely regulated.

Technology Performance

A field technology demonstration was conducted in the Spring of 1993 at Bangor Subase in Washington. A full-scale system will be designed as part of the effort to contain the migrating plume. The pump and treat effort is a part of the Interim Remedial Action for the Bangor site.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This process was demonstrated at Bangor SUBASE in Washington.

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Other Physical Treatment

Advanced Oxidation Process VOCs in Ground Water

Technology Description

This technology employs the oxidative power of the different advanced oxidation processes (AOPs) to destroy organic contaminants in ground water. The AOPs involve using ultraviolet (UV) radiation, hydrogen peroxide, and ozone in various combinations to generate hydroxyl radicals to destroy the target organics. Although UV, hydrogen peroxide, and ozone have oxidative power individually, the hydroxyl radical reactions are the most important.

Based on laboratory study findings, a two-staged approach was developed for an on-site demonstration of the AOP technology. This approach exploited the varied reaction conditions of different AOPs to optimize the organics destruction efficiency. The two stages involved first applying ozone/peroxide at high pH and secondly ozone/UV at low pH. A third stage using peroxide/UV was also tested as a polishing stage and to provide added assurance for a clean discharge.

This technology demonstration was targeted at treating ground water contaminated with organic pollutants from past fire fighting exercises. The pollutants came from aqueous film foam (AFFF), a fire fighting agent; various fuels; and other combustible materials used in the exercises. The pollutants detected included chlorinated hydrocarbons and fuel components. The contaminant concentrations in the ground water ranged from 50 to 100 ppm measured as Total Organic Carbon (TOC).

Technology Performance

The on-site technology demonstration was completed in 1991 at a U.S. Navy site in Lakehurst, New Jersey. It was demonstrated that the AOP was effective in the destruction of individual contaminants as well as TOC, and that a one-stage AOP system may be adequate for trace contaminant removal.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This process was demonstrated at a U.S. Navy site in Lakehurst, New Jersey.

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Other Physical Treatment

Air Sparging VOCs in Ground Water (*In Situ* Treatment)

Technology Description

This technology allows VOCs to be removed from the aquifer without removing the contaminated water. The system provides a means to convert a ground water contamination problem into a vapor stream that can be easily treated at the surface.

The process creates an in-well air stripped that volatilizes VOCs contained in the ground water and removes them as a vapor. The vapor is then extracted under a vacuum and treated at the surface. The system consists of a special well design that is a well within a well. The inner well extends from the surface into the unsaturated zone and is screened in the zone of contamination. The outer well extends from the surface through the vadose zone and may terminate above the water table. This outer well may be screened in the vadose zone so it can be used for soil vapor extraction. A gas injection line is placed in the inner well and releases bubbles in the well at an elevation beneath the zone of contamination. The bubbles rise in the well and collect VOCs that are naturally transferred from the liquid phase to the gas bubbles. The bubbles and water rise within the well until they hit a packer which is placed in the inner well above the elevation of the water table. The inner well is screened just below the packer, allowing the water and bubble mixture to escape into the annular space between the inner and outer well. The water falls down the annular space and is returned to the water table. The gas bubbles pop and are vacuumed off via a vacuum line extending from the surface into the annular space.

The system recirculates the ground water through air-lift pumping. The air-lift pumping creates a ground water circulation cell in which the ground water becomes cleaner and cleaner with each pass through the in-well air stripper.

This system eliminates the need for handling contaminated water above ground and for disposing or storing partially treated water. There is no need for an above-ground air stripping tower or storage tanks to contain tritiated water that is free of VOCs.

This method allows for recirculating surfactants and catalysts, if needed. In addition, a single well can be used for extraction of soil vapors as well as for ground water remediation.

Technology Performance

This technology will be demonstrated over the next two to three years at DOE's Hanford Reservation as part of the agency's Integrated Technology Demonstration Program for Arid Sites.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology will be demonstrated at DOE's Hanford Reservation, which comprises about 560 square miles in the southeastern part of Washington State.

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Catalytic Decontamination Volatile Organic Compounds (VOCs) in Ground Water

Technology Description

This catalytic decontamination process is a closed system that treats VOCs in ground water producing innocuous end products. This technology can be useful when cross-media transfer of the contamination, which may occur with other processes, such as air stripping, is unacceptable. This technology is primarily a ground water restoration technique, although surface water can be treated as well. It is especially applicable for highly contaminated waters such as leachates.

The system used in the pilot study consists of two "loops." The first loop consists of air drying, ozone generation, and injection of the ozone into the vapor-liquid contact tank. Air effluent passes through a catalytic destruction unit and returns to the air drier. The second loop is open and consists of a water inlet from the ground water source, pretreatment, introduction into the vapor-liquid contact tank, and discharge. The water pretreatment might consist of filtering, water softening, iron removal, or defoaming.

This technology has a number of advantages:

- The process is closed circuit, i.e., there is no air effluent;
- It operates at negative air pressure, thus, reducing the risk of accidental contamination due to leaks; and
- It is a destructive, rather than a cross-media transfer technique.

Despite these advantages, this technology also has limitations:

- The method might not be cost effective with respect to methods that have air effluents;
- When treating high concentrations, a potentially large consumption of ozone will result;
- When treating anoxic leachates, reduced metal compounds are likely to be present;
- These reduced metal compounds will react with the ozone and can form insoluble precipitates as well as result in large ozone consumption;
- The metal precipitates could require extensive system cleaning;
- The method requires considerable energy for the generation of UV light, dry air, ozone, pumps, and blowers; and
- Biofouling can occur on the UV light tubes.

Technology Performance

The results from a small-scale pilot test conducted at Fort Dix, New Jersey were both positive and negative:

- Although total organic carbon concentration was not reduced, the concentration of volatile halogenated organics (VHO) was reduced up to 90 percent; and

- Without the inclusion of UV light in the treatment, the VHO concentration was reduced, but methylene chloride was not affected and dichloroethanes were not reduced below detection limits.

Remediation Costs

Based on limited experience to date, the operating and maintenance costs of this method have not been developed in detail, but are expected to be in the range of \$1 to \$8/1,000 gal, depending upon the concentration of the contaminants and the amount of pretreatment required. Equipment for treating 50,000 gal/day of ground water, with an organic halide concentration in the range of 75 to 100 g/L, would cost in the range of \$150,000 to \$200,000, without installation.

General Site Information

A small-scale pilot testing (1 to 10 drums) has been conducted at Fort Dix, New Jersey.

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Other Physical Treatment

CAV-OX® Process Organics in Ground Water and Wastewater

Technology Description

The CAV-OX® process uses a synergistic combination of hydrodynamic cavitation and ultraviolet radiation to oxidize contaminants in water. The process is designed to remove organic contaminants from waste streams and groundwater without releasing volatile gaseous organic compounds. Treatment costs using the CAV-OX® process are estimated by the developer to be about half the cost of advanced ultraviolet (UV) oxidation systems and substantially less expensive than carbon absorption. In addition, because the process equipment has only one moving part, maintenance costs are minimal. The process is designed to achieve reduction levels necessary for meeting discharge specifications for most aqueous contaminants. The CAV-OX® process cannot handle free product or highly turbid waste streams, because these conditions tend to lower the efficiency of the ultraviolet reactor; however, the CAV-OX® cavitation chamber itself is unaffected in such cases.

Free radicals are generated and maintained by the system's combination of cavitation, UV excitation, and where necessary, the addition of hydrogen peroxide and metal catalysts. Neither the cavitation chamber nor the UV lamp or hydrogen peroxide reaction generates toxic by-products or air emissions. UV lamp output can be varied from 60 watts to over 15,000 watts, depending on the contaminant stream.

The process is designed to treat liquid waste, specifically groundwater or wastewater contaminated with organic compounds. Organics such

as benzene can be treated to non-detectable levels; others such as 1,1-dichloroethane are treated typically to 96 percent removal efficiencies. Living organisms such as *salmonella* and *E. Coli* are also significantly reduced.

Technology Performance

The CAV-OX® process has been tested at several private and public sites. Recent tests at a Superfund site treated leachate containing 15 different contaminants. PCP, one of the major contaminants, was reduced by 96 percent in one test series. In other tests, the process has successfully treated cyanide contamination.

This technology was accepted into the EPA SITE Demonstration Program in summer 1992. The demonstration was conducted in March 1993 at Edwards Air Force Base in Edwards, California.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

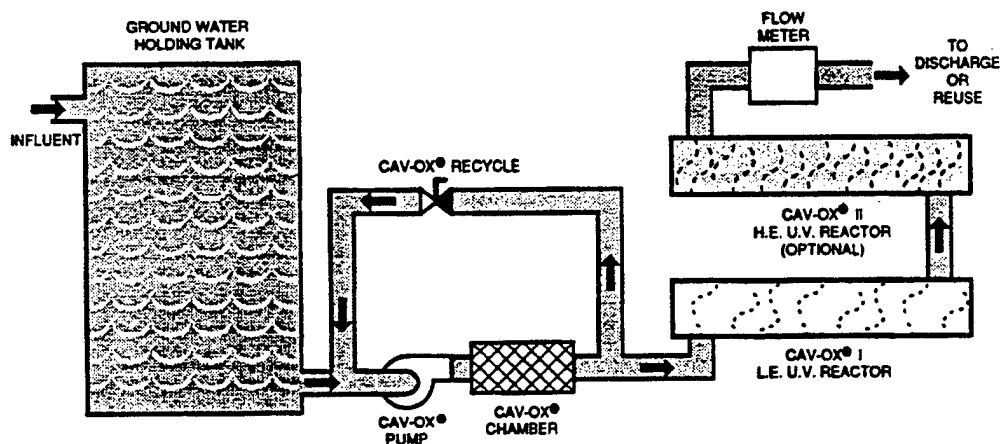
This process has been tested at several private and public sites, including the San Bernardino and Orange County, California, Water Departments. The SITE Program demonstration was conducted at Edwards Air Force Base in Edwards, California.

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The CAV-OX® Process



Other Physical Treatment

Chemtact™ Gaseous Waste Treatment **Organics and Inorganics in Gaseous Waste Streams**

Technology Description

The Chemtact™ system uses gas scrubber technology to remove organic and inorganic contaminants from gaseous waste streams. Atomizing nozzles within the scrubber chamber disperse droplets of a controlled chemical solution. Very small droplet sizes, less than 10 microns, and a longer retention time than in traditional scrubbers result in a once-through system that generates low volumes of liquid residuals. These residuals are then treated by conventional techniques.

Gas scrubbing is a volume reduction technology that transfers contaminants from the gas phase to a liquid phase. The selection of absorbent liquid is based on the chemical characteristics of the contaminants.

Three mobile units are currently available: (1) a one-stage, 2,500-ft³/min system; (2) a two-stage, 800-ft³/min system; and (3) a three-stage, 100-ft³/min system. The equipment is trailer-mounted and can be transported to waste sites.

Performance tests treating benzene, toluene, xylene, and other hydrocarbons have shown removal in the 85 to 100 percent range. Pure streams are easier to adjust to obtain high removals. In addition, phenol and formaldehyde emission control tests indicate approximately 94 percent removals.

This technology can be used to treat gaseous waste streams containing a wide variety of organic or inorganic contaminants, but it is best suited for VOCs. The system can be used with

source processes that generate a contaminated gaseous exhaust, such as air stripping of groundwater or leachate, soil aeration, or exhaust emissions from dryers or incinerators.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1989. The developer has several installations in operation for VOC removal. The developer is also conducting treatability studies and making appropriate system modifications.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

Site information was not provided for this publication.

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Other Physical Treatment

Contained Recovery of Oily Wastes (CROW™) Process Coal Tar Derivatives and Petroleum By-products in Soil (*In Situ* Treatment)

Technology Description

The contained recovery of oily wastes (CROW™) process recovers oily wastes from the ground by adapting a technology presently used for secondary petroleum recovery and for primary production of heavy oil and tar sand bitumen. Steam and hot-water displacement are used to move accumulated oily wastes and water to production wells for above ground treatment.

Injection and production wells are first installed in soil contaminated with oily wastes. Low-quality steam is then injected below the deepest penetration of organic liquids. The steam condenses, causing rising hot water to dislodge and sweep buoyant organic liquids upward into the more permeable soil regions. Hot water is injected above the impermeable soil regions to heat and mobilize the oil waste accumulations. The mobilized wastes are recovered by hot-water displacement.

When the oily wastes are displaced, the organic liquid saturations in the subsurface pore space increase, forming an oil bank. The hot water injection displaces the oil bank to the production well. Behind the oil bank, the oil saturation is reduced to an immobile residual saturation in the subsurface pore space. The oil and water produced are treated for reuse or discharge.

In situ biological treatment may follow the displacement and is continued until ground water contaminants are no longer detected in any water samples from the site. During treatment, all mobilized organic liquids and water-soluble contaminants are contained within the

original boundaries of oily waste accumulations. Hazardous materials are contained laterally by ground water isolation, and vertically by organic liquid flotation. Excess water is treated in compliance with discharge regulations.

The process removes large portions of oily waste accumulations; stops the downward and lateral migration of organic contaminants; immobilizes any residual saturation of oily wastes; and reduces the volume, mobility, and toxicity of oily wastes. It can be used for shallow and deep contaminated areas and uses readily available mobile equipment.

This technology can be applied to manufactured gas plants, wood-treating sites, petroleum-refining facilities, and other sites with soils containing light to dense organic liquids, such as coal tars, pentachlorophenol solutions, creosote, and petroleum by-products.

Technology Performance

This technology was tested both at the laboratory and pilot-scale under the EPA SITE Emerging Technology Program. The program showed the effectiveness of the hot-water displacement and displayed the benefits from the inclusion of chemicals with the hot water. The final report for the Emerging Technology Program was submitted to EPA.

Based on results of this project in the Emerging Technology Program, this technology was invited to participate in the SITE Demonstration Program. The technology was demonstrated at

the Pennsylvania Power and Light (PP&L) Brodhead Creek site at Stroudsburg, Pennsylvania in early 1993. The site contains an area having high concentrations of by-products from a former operation. All documentation and site plans are being prepared.

Sponsors for this program, in addition to EPA and PP&L, are the Gas Research Institute, the Electric Power Institute, and the U.S. Department of Energy. Remediation Technologies, Inc., will assist Western Research Institute in operation of the technology for demonstration, with emphasis on the treatment of the produced fluids for disposal.

This technology has also been demonstrated on a pilot scale at a wood treatment site in Minnesota. Removal of nonaqueous phase liquids in the pilot test was the same as that predicted by treatability studies. Full-scale remediation of this site was planned for mid-1993.

Remediation Costs

Cost information was not provided for this publication.

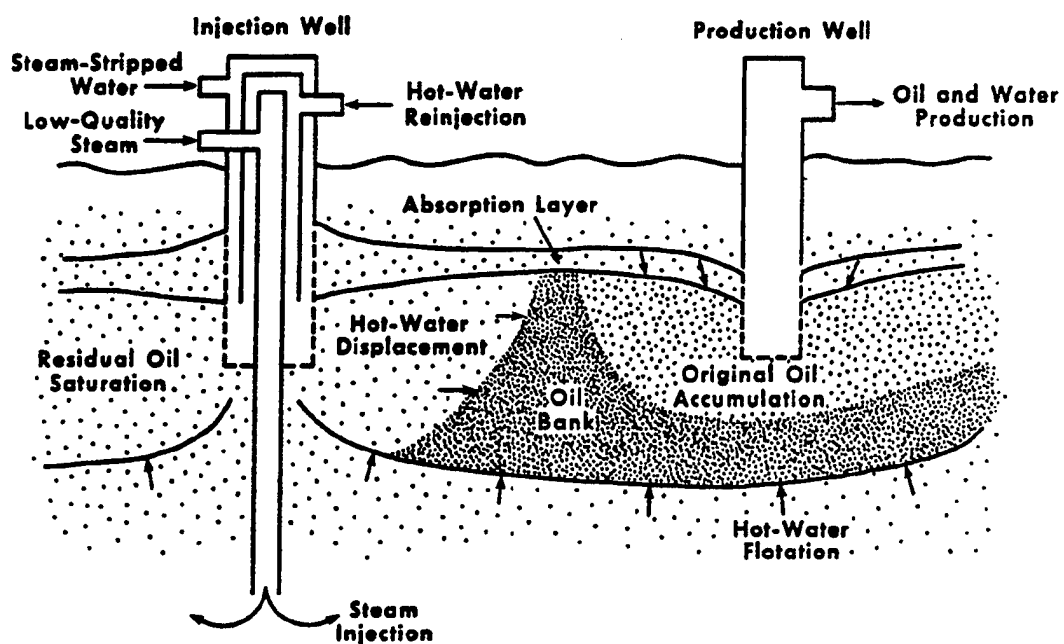
General Site Information

This technology was scheduled to be demonstrated at the Pennsylvania Power and Light (PP&L) Brodhead Creek site in Stroudsburg, Pennsylvania.

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CROW™ Subsurface Development



Other Physical Treatment

Electrochemical Reduction and Immobilization Hexavalent Chromium and Other Heavy Metals in Ground Water (*In Situ* Treatment)

Technology Description

This process uses electrochemical reactions to generate ions for removal of hexavalent chromium and other metals from groundwater. As contaminated water is pumped from an aquifer through the treatment cell, electrical current passes from electrode to electrode through the process water. The electrical exchange induces the release of ferrous and hydroxyl ions from opposite sides of each electrode. A small gap size coupled with the electrode potentials of hexavalent chromium and ferrous ion causes the reduction of hexavalent chromium to occur almost instantaneously. Depending on the pH, various solids may form. They include chromium hydroxide, hydrous ferric oxide, and a chromium-substituted hydrous iron complex.

For *in situ* chromate reduction to occur, a slight excess of ferrous iron must be provided. This concentration is based on the hexavalent chromium concentration in the groundwater, site-specific hydraulics, and the desired rate of site cleanup. Dilution is avoided by introducing ferrous ions *in situ* and using the aquifer's water to convey them. Following their injection, soluble ferrous ions circulate until they contact either chromate containing solids or chromate ions. In conventional pump and treat schemes, chromate dragout results in long treatment times. Through *in situ* reduction of chromates adsorbed on the soil matrix and contained in precipitates, treatment times should be reduced by more than 50 percent.

If implemented properly under favorable pH conditions, complete chromate reduction can be

achieved without the need for sludge handling. As chromate reduction occurs, iron and chromium solids are filtered out and stabilized in the soil. When precipitates are not formed due to unfavorable pH, the system could easily be applied to a pump and treat process and operated until chromium removal goals are achieved. Eliminating dragout shortens system life and minimizes sludge handling. Another option is to combine a pump-and-treat scheme with *in situ* chromate reduction to maximize the cleanup rate, reduce aquifer contaminant loads, and provide water for irrigation or industry.

Another benefit of this method is that hydrous iron oxide adsorbs heavy metals. When iron solids are immobilized in the soil, the concentrations of other contaminants in the ground water decrease significantly because of adsorption and co-precipitation.

The pilot plant is designed to treat ground water contaminated with hexavalent chromium in concentrations of 1 to 50 ppm and other heavy metals (2 to 10 ppm), including zinc, copper, nickel, lead, and antimony. A full-scale system can be engineered to handle any flow rate as well as elevated contaminant loads. Each system will be site-specific and designed to achieve all remediation objectives.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1992. The process was evaluated in early 1993 at a site where Andco has an operating ground water

treatment system. Although the process can be used for remediation of both confined and unconfined aquifers, water from an unconfined source was treated during the demonstration.

The Kerr-McGee Chemical Corp. site is contaminated with hexavalent chromium as a result of using sodium dichromate in production processes. Ground water is being treated by the electrochemical process at a rate of 50 to 120 gpm. After treatment, clean water is reinjected into the ground through an infiltration trench downgradient of the site.

Remediation Costs

Cost information was not provided for this publication.

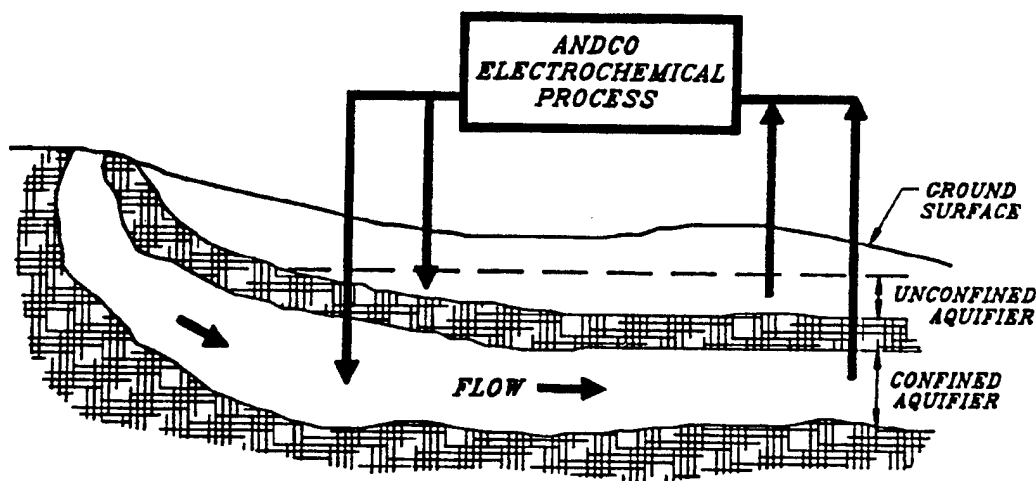
General Site Information

This technology was demonstrated at the Kerr-McGee Chemical Corporation site in Wisconsin.

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Electrochemical In Situ Chromate Reduction and Heavy Metal Immobilization Process



Other Physical Treatment

Filtration Heavy Metals and Radionuclides in Waters

Technology Description

The colloid sorption filter is a "polishing" filtration process that removes inorganic heavy metals and non-tritium radionuclides from industrial wastewater and ground water. The filter unit employs inorganic, insoluble beads/particles (Filter Flow-1000) contained in a dynamic, flow-through configuration resembling a filter plate. The pollutants are removed from the water via sorption, chemical complexing, and hydroxide precipitation. By employing site-specific optimization of the water chemistry prior to filtration, the methodology removes heavy metal and radionuclide ions, colloids, and colloidal aggregates. A three-step process is used to achieve heavy metal and radionuclide removal. First, water is treated chemically to optimize formation of colloids and colloidal aggregates. Second, a prefilter removes the larger particles and solids. Third, the filter bed removes the contaminants to the compliance standard desired. By controlling the water chemistry, water flux rate, and bed volume, the methodology can be used to remove heavy metals and radionuclides in a few to several hundred gpm.

The process is designed for either batch or continuous flow applications at fixed installations or for field mobile operations. The field unit can be retrofitted to existing primary solids water treatment systems or used as a polishing filter for new installations or on-site remediation applications.

The methodology has applications for heavy metal and radionuclide remediation from pond

water, tank water, ground water, or for in-line industrial wastewater treatment systems. The technology also has been successful in removing natural occurring radioactive materials (NORM), man-made low level radioactive wastes (LLRW) and transuranic (TRU) pollutants from ground water and wastewater.

Technology Performance

The methodology was accepted into the EPA SITE Demonstration Program in July 1990. EPA and the Department of Energy (DOE) are co-sponsoring the technology evaluation. Bench tests have been conducted at the DOE Rocky Flats Facility, Golden, Colorado, using ground-water samples contaminated with heavy metals and radioactive materials.

Remediation Costs

Capital cost for a trailer plus unit (25 gpm) is about \$150,000; operational costs are about \$1.50 to \$2.00/1,000 gallons processed.

General Site Information

Bench-scale tests have been conducted at DOE's Rocky Flats Facility in Golden, Colorado.

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FORAGER® Sponge **Heavy Metals in Waters**

Technology Description

The FORAGER® sponge is an open-celled cellulose sponge incorporating an amine-containing polymer that has a selective affinity for aqueous heavy metals in both cationic and anionic states. The polymer prefers to form complexes with ions of transition-group heavy metals, providing ligand sites that surround the metal and form a coordination complex. The polymer's order of affinity for metals is influenced by solution parameters such as pH, temperature, and total ionic content.

The removal efficiency for transition-group heavy metals is about 90 percent at a flow rate of 1 bed volume/minute. The highly porous nature of the sponge speeds diffusional effects, thereby promoting high rates of ion absorption. The sponge can be used in columns, fishnet-type enclosures, or rotating drums. When using column operations, flow rates of 3 bed volumes/minute can be obtained at hydrostatic pressures only 2 feet above the bed and without additional pressurization. Therefore, sponge-packed columns are suitable for unattended field use.

Absorbed ions can be eluted from the sponge using techniques typically employed to regenerate ion exchange resins and activated carbon. Following elution, the sponge can be used in the next absorption cycle. The number of useful cycles depends on the nature of the absorbed ions and the elution technique used. Alternatively, the metal-saturated sponge can be incinerated. In some cases, it may be preferable to compact the sponge by drying it to an extremely small volume to facilitate disposal.

The sponge can scavenge metals in concentration levels of ppm and ppb from industrial discharges, municipal sewage process streams, and acid mine drainage waters.

When remediating ground water, elongated nets that confine the sponge are placed in wells and removed when saturated.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1991. The sponge has been found effective in removing trace heavy metals from acid mine drainage waters at three locations in Colorado.

In bench-scale tests, mercury, lead, nickel, cadmium, and chromium have been reduced to below detectable levels at Superfund sites.

In a field-scale installation at a photoprocessing operation that generates an aqueous effluent having 6 lbs/day of chromate and 0.8 lbs/day of silver, 75 percent reductions were achieved at a cost of \$1,100/month.

The sponge will be demonstrated, alone or as part of CH2O Company's E-Process. The National Lead Industry site in Pedricktown, New Jersey, has been identified as the demonstration site. Treatability tests were conducted in April 1993.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The SITE Program demonstration of this technology is tentatively scheduled for the National Lead Industry site in Pedricktown, New Jersey, in September/October 1993.

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Other Physical Treatment

Hydraulic Fracturing Organics and Inorganics in Soil

Technology Description

Hydraulic fracturing is a method of creating tabular lenses of granular material in soil or rock. The technology is designed to enhance remediation in low permeability geologic formations. This technology has been developed for EPA's Risk Reduction Engineering Laboratory by the University of Cincinnati (UC) at the Center Hill facility under the EPA SITE Demonstration Program.

A hydraulic fracture is created when fluid is pumped down a borehole until a critical pressure is reached and the enveloping soil fractures. Sand-laden slurry is pumped into the fracture as it propagates away from the borehole, creating a highly permeable pathway for delivery or recovery of fluids in the subsurface. In over-consolidated soil, the fractures propagate in a horizontal to sub-horizontal plane. They are 1 to 3 centimeters thick and as much as 14 meters in diameter. In general, they are slightly elongate in plan and asymmetric with respect to their parent borehole. Fracture growth is monitored by measuring the deformation of the ground surface using a surveyor's level or a recently developed laser system that displays uplift in real time.

Hydraulic fracturing provides little remedial effect on its own, but it offers potential for dramatically improving the effectiveness of most remedial technologies that require fluid flow in the subsurface. These include soil vapor extraction, bioremediation, soil washing, and pump-and-treat.

The technology also can be used to enhance bioremediation. has the potential for delivery of solids to the subsurface. Nutrients or oxygen-releasing compounds, can be added to the slurry as granules and injected into contaminated soil.

Technology Performance

The technology entered the EPA SITE Demonstration Program in 1991. Pilot-scale demonstrations have been conducted in Oak Brook, Illinois, and Dayton, Ohio. The Oak Brook site is contaminated with organic solvents, and soil vapor extraction has been used since 1991 to remove VOCs. Hydraulic fractures were created in two of the four wells, at depths of 6, 10, and 15 ft below ground surface. The vapor flow rate, soil vacuum, and contaminant yield from the fractured and unfractured wells were monitored regularly. Results obtained include the following:

- Over a one-year period, the vapor yield from hydraulically fractured wells was an order of magnitude greater than from unfractured wells.
- The hydraulically fractured wells enhanced remediation over an area 30 times greater than the unfractured wells.
- The presence of pore water decreased the vapor yield from wells; water filtration into areas where vapor extraction is being conducted must be prevented.

The Dayton site, an underground storage tank spill, is contaminated with BTEX and other petroleum hydrocarbons. *In situ* bioremediation

is being used for cleanup. In August 1991, hydraulic fractures were created in one of two wells at 4, 6, 8, and 10 ft below ground surface. Sampling was conducted before the demonstration and twice during the demonstration at locations 5, 10, and 15 ft north of the fractured and unfractured wells. Results obtained include the following:

- The flow of water into the fractured well was two orders of magnitude greater than in the unfractured well.
- The rate of bioremediation near the fractured well was 75 percent higher for BTEX and 77 percent higher for TPH compared to rates near the unfractured well.

Remediation Costs

Based on developer estimates, capital costs for this technology range from \$80,100 to \$94,900 depending on whether laser surveying equipment associated with the Ground Elevation Measurement System (GEMS) is used. Per-day operating costs (four to six fractures/day) total \$6,185 or from \$1,030 to \$1,550/fracture.

General Site Information

This technology was demonstrated at a solvent-contaminated site in Oak Brook, Illinois, and at a site contaminated with diesel fuel and heating oil in Dayton, Ohio. EPA's Technology Evaluation Report and Applications Analysis Report will be available late in 1993.

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MAECTITE™ Process

Lead in Soils, Sludges, Other Waste Materials, and Debris

Technology Description

This two-step process converts leachable lead into soluble mineral crystals. The process makes lead-contaminated wastes, that are classified as hazardous under RCRA, non-hazardous and acceptable for landfilling as a special waste. Seven full-scale projects have been completed to date.

The first step in the process involves blending a proprietary powder with lead-contaminated material. A proprietary reagent solution then is blended into the mixture. The curing time at normal temperature and pressure is about 4 hrs. Testing has shown that the final product passes EPA's paint filler test, TCLP criteria, and other EPA tests such as the Multiple Extraction Procedure and the Acid-Leach Procedure. The system can treat up to 100 tons/hr.

Since the process is a chemical treatment technology, specialty equipment, instruments, and a mobile field laboratory are required to document the chemical control process and optimize treatability trials during full-scale remediation and to test treated material to make sure the end product passes regulatory criteria and meets treatment objectives. Equipment for existing mobile processing may include a grizzly-shredder conveyor, a weightbelt conveyor, mixers, powder silos and delivery system, and MAEPRIC storage and dosing pumps and water sprays. The project size and waste matrix characteristics usually determine the system configuration.

The mobile technology treats lead-contaminated wastes and soils from manufacture and use of storage batteries, pigments, leaded glass, fuel additives, photographic materials, primary and secondary lead smelting operations, and batteries. The process can treat wastes from sites that vary in composition from gravel to sandy soil, clay soil, sediments, and sludge to battery casings, baghouse dusts, and incinerator ash. The developer has processed nearly 40,000 tons of lead-contaminated soils, sludges, slurries, baghouse dusts, and other materials that are RCRA-hazardous due to leachable lead levels. Most lead-contaminated waste materials and debris that fail TCLP criteria for lead are suitable for this treatment.

The process produces a material typical of soil in appearance and of reduce volume. No by-products or sidestreams are generated because the technology uses decontamination wastewaters to dilute the proprietary reagent.

Technology Performance

This technology was accepted into EPA's SITE Demonstration Program in 1991. In 1992, the process was formally accepted into EPA's Pre-Qualified Offerers Procurement Strategy (PQOPS) program. It was successfully applied at full scale in EPA's first PQOPS competitively awarded contract site in Sioux Falls, South Dakota.

The process has been proven effective at the bench and pilot scales for more than 30 types of waste material, including leadbird and backshot.

The full-scale process is cost effective and has been demonstrated at six other full-scale sites in Wisconsin, Michigan, Indiana, Ohio, and Virginia.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology has been demonstrated at full scale at sites in Indiana, Michigan, Ohio, South Dakota, Virginia, and Wisconsin.

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Other Physical Treatment

Membrane Microfiltration **Heavy Metals, Cyanide, and Uranium in Liquids** **and Inorganics, Organics, and Oily Wastes in Solids**

Technology Description

This system is designed to remove solid particles from liquid wastes, forming filter cakes typically ranging from 40 to 60 percent solids. The system can be manufactured as an enclosed unit, requires little or no attention during operation, is mobile, and can be trailer-mounted.

The membrane microfiltration system uses an automatic pressure filter, combined with a special Tyvek filter material (Tyvek T-980) made of spun-bound olefin. The filter material is a thin, durable plastic fabric with tiny openings (about 1 ten-millionth of a meter in diameter) that allow water, other liquid, and soil particles smaller than the openings to flow through. Solids in the liquid stream that are too large accumulate on the filter and can be easily collected for disposal.

The automatic pressure filter has an upper chamber for feeding waste through the filter and a lower chamber for collecting the filtered liquid (filtrate). At the start of a filter cycle, the upper chamber is lowered to form a liquid-tight seal against the filter. The waste feed then is pumped into the upper chamber and through the filter. Filtered solids accumulate on the Tyvek surface forming a filter cake, while filtrate is collected in the lower chamber. Following filtration, air is fed into the upper chamber at a pressure of about 45 psi. Air is used to remove any liquid remaining in the upper chamber and to further dry the cake. When the cake is dry, the upper chamber is lifted, and the filter cake is automatically discharged. Clean filter materi-

al is then drawn from a roll into the system for the next cycle. Both the filter cake and the filtrate can be collected and treated further prior to disposal, if necessary.

This treatment can be applied to hazardous waste suspensions, particularly liquid heavy metal- and cyanide-bearing wastes; ground water contaminated with heavy metals; constituents such as landfill leachate; and process wastewaters containing uranium. The technology is best suited for treating wastes with solid concentrations of less than 5,000 ppm. At higher concentrations, the cake capacity and handling become limiting factors. The system can treat any type of solids, including inorganics, organics, and oily wastes, with a wide variety of particle sizes. Moreover, the system is capable of treating liquid wastes containing volatile organics because the unit is enclosed.

Technology Performance

This technology was demonstrated at the Palmerton Zinc Superfund site in Palmerton, Pennsylvania. The shallow aquifer at the site, contaminated with dissolved heavy metals—such as cadmium, lead, and zinc—was selected as the feed waste. The system treated the waste at a rate of 1 to 2 gpm.

The demonstration was conducted over a 4-week period in 1990. EPA has completed an Applications Analysis Report (EPA/540/A5-90/007), a Technology Evaluation Report (EPA/

540/5-90/007), and a videotape of the demonstration.

Following is a summary of results of the demonstration:

- Removal efficiencies for zinc and total suspended solids ranged from 99.75 to 99.99 percent; the average was 99.95 percent;
- Solids in the filter cake ranged from 30.5 to 47.1 percent;
- Dry filter cake in all test runs passed the RCRA paint filter liquids test;
- Filtrate met the applicable NPDES standard for zinc;
- A composite filter cake sample passed the extraction procedure (EP) and TCLP tests for metals.

Remediation Costs

An economic analysis was conducted of a 2.4-ft² unit, similar to the one used during the SITE demonstration, and a 36-ft² unit. The analysis assumed the system would operate continuously (24 hr/day, 7 days/wk) for one year. Annual operation and maintenance costs were estimated to be \$213,000 and \$549,100 for the 2.4-ft² and 36-ft² units, respectively, with

corresponding annual throughputs of 525,000 gal and 7,884,000 gal. The cost analysis assumed that the filter cake and filtrate would be disposed of as non-hazardous wastes. One-time capital costs were \$369,300 for the smaller unit and \$1,251,200 for the larger one.

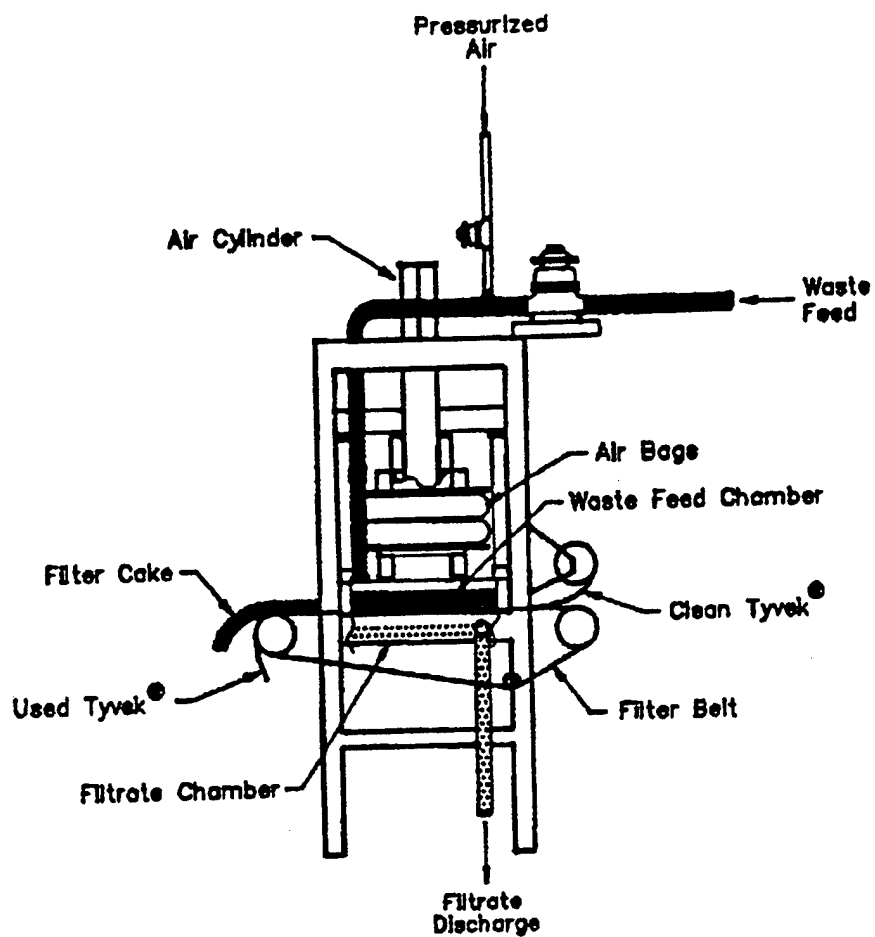
General Site Information

This technology was demonstrated at the Palmerton Zinc Superfund site in Palmerton, Pennsylvania. The site has a shallow aquifer that is contaminated with dissolved heavy metals.

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Membrane Microfiltration Process



Other Physical Treatment

Membrane Separation Organics in Ground Water

Technology Description

This hazardous waste treatment system consists of a hyperfiltration unit that extracts and concentrates contaminants from a variety of waste streams—including ground water, surface water, storm water, landfill leachates, and industrial process wastewater. The hyperfiltration unit removes and concentrates contaminants by pumping contaminated liquids through porous stainless steel tubes coated with specially formulated membranes. Contaminants are collected inside the tube membrane, while “clean” water permeates the membrane and tubes. Depending on local requirements and regulations, the clean permeate can be discharged to the sanitary sewer for further treatment at a publicly owned treatment works (POTW). The concentrated contaminants are collected in a holding tank.

Technology Performance

The membrane filtration system was demonstrated under EPA's SITE Demonstration Program in 1991 at the American Creosote Works in Pensacola, Florida. Results confirmed that this membrane system removed 95 percent of the PAH contamination and 25 to 30 percent of smaller phenolic compounds. This resulted in an overall 80 percent reduction of creosote constituents from the contaminated feed. PAH removal was sufficient to pass local POTW discharge standards. Demonstration of a bioremediation unit was canceled.

Remediation Costs

The total annual cost to operate a 12-module filtration unit ranges between \$514,180 and \$1,209,700, depending on whether effluent treatment and costs are considered, the flow rate through the unit, the cleanup requirements, and the cost of effluent treatment and disposal (if required). Effluent treatment and disposal costs, if considered, could account for up to 60 percent of the total cost. Labor can account for up to 40 percent. Processing costs are more dependent on labor costs than equipment costs.

The cost of this technology has been calculated for flow rates of 24 gpm, 12 gpm, and 7.2 gpm. With effluent treatment, costs are \$228 to \$522/1,000 gal, \$456 to \$1,044/1,000 gal, and \$760 to \$1,739/1,000 gal, respectively. Without effluent treatment, these costs are \$222/1,000 gal, \$444/1,000 gal, and \$739/1,000 gal, respectively.

General Site Information

The membrane filtration system was demonstrated under EPA's SITE Demonstration Program in 1991 at the American Creosote Works in Pensacola, Florida.

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Other Physical Treatment

Pneumatic Fracturing ExtractionSM and Hot Gas Injection VOCs and Semi-VOCs in Soil and Rock

Technology Description

An integrated treatment system incorporating Pneumatic Fracturing ExtractionSM (PFESM) and Hot Gas Injection (HGI) has been jointly developed by Accutech Remedial Systems Inc., and the Hazardous Substance Management Research Center located at the New Jersey Institute of Technology in Newark, New Jersey. The system provides a cost-effective accelerated remedial approach to low permeability formations contaminated VOCs and SVOCs. By forcing compressed gas into a formation at pressures that exceed the natural *in situ* stresses present, a fracture network is created. These fractures allow subsurface air to circulate faster and more efficiently through the formation, which can greatly improve the rates of contaminant mass removal. The fracturing technology also increases the effective area that can be influenced from each extraction well while intersecting new pockets of contamination that previously were caught in the formation. Thus, contaminants are removed faster and from a larger section of the formation than was previously feasible.

The fracturing process coupled with an *in situ* thermal process called Hot Gas Injection (HGI) to further enhance contaminant removal. HGI puts the energy generated during catalytic oxidation of the contaminants back into the ground. For sites with chlorinated compounds, a special catalyst, which can cost-effectively treat halogenated organics, is used for the oxidation process. The heat from the process warms up the formation to significantly raise the vapor pressure of the contaminants present.

Thus, the contaminants volatilize faster, making cleanup more efficient.

The integrated treatment system is cost-effective for treating soils and rock where conventional *in situ* technologies are limited in their effectiveness because of the presence of low permeability geologic formations. Halogenated and non-halogenated VOCs and SVOCs can be remediated by this system. Activated carbon is used when contaminant concentrations decrease to levels where catalytic oxidation is no longer cost-effective.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1990. The demonstration was conducted in 1992 at a New Jersey Department of Environmental Protection and Energy Environmental Cleanup Responsibility Act (ECRA) site in Hillsborough, New Jersey, where TCE, among other VOCs, was removed from a fractured siltstone formation. Site characteristics and the extent of contamination limited the demonstration to the comparison of results from short term (1 to 4 hr) vacuum extraction experiments before and after fracturing of the formation. To evaluate hot gas injection, hot air (about 200°F) generated by compression heating was injected into one well in the formation while extracting from one or more other wells. Results of the demonstration include the following:

- The process increased the extracted air flow by more than 600 percent relative to that

achievable in this formation prior to fracturing.

- While TCE concentration in the extracted air remained approximately constant (about 50 ppmv), the increased air flow rate resulted in TCE mass removal rates after fracturing that were an average of at least 675 percent higher over the 4-hr tests.
- Significantly increased extracted air flow rates (700 to 1,400 percent) were observed in wells 10 ft from the fracturing well. Even in wells 20 ft away, increases in air flow rates of 200 to 1,100 percent were observed. Coupled with well pressure data and tiltmeter data for surface heave, these results suggest an effective extraction radius of at least 20 ft.
- Even higher increases in air flow rates and TCE mass removal rates were observed when one or more of the monitoring wells were opened to allow passive air inlet. Under these conditions, air flow rates increased an average of 19,000 percent and TCE mass removal rates increased 2,300 percent.
- The results of the hot gas injection experiments were inconclusive. While some increase in the soil gas temperature in the formation was observed, it is unclear that this was accompanied by improvements in TCE mass removal.

Remediation Costs

According to EPA, a cost of \$140/lb of TCE removed was estimated for a remediation of the demonstration site or a comparable site. This estimate was based on capital and operating cost data provided by the developer and several assumptions characterized as "very optimistic."

General Site Information

This technology was demonstrated at a New Jersey Department of Environmental Protection and Energy Environmental Cleanup Responsibility Act (ECRA) site in Hillsborough, New Jersey.

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Other Physical Treatment

Precipitation/Filtration Radionuclides in Ground Water

Technology Description

This technology is designed to remove low to moderate levels of naturally occurring radioactive materials (NORM) from contaminated water. Other potential applications of the technology include cleaning up NORM-contaminated liquid wastes from industrial and oil-drilling operations and contaminated ground water at nuclear facilities.

The technology removes contaminants through chemical complexing, adsorption, and absorption. The system uses a proprietary complexing agent, URAL, which is an insoluble granular material. As the URAL is combined with contaminated water, the NORM begins to form solids. Solids are removed as sludge by precipitation and filtration. For the EPA SITE Program demonstration, precipitated solids formed will be collected in drums and temporarily stored on site before disposal at an authorized off-site facility.

Primary components of the technology are the pump, URAL feed unit, and the process unit. The pump delivers contaminated water through the URAL feed line, where URAL is introduced. The water and URAL mixture then is fed into the process unit, where mixing, precipitation, and clarification take place. The NORM precipitate collects in the bottom of the process unit and is removed continuously by a precipitate removal pump and stored in drums. To meet regulatory discharge standards, hydrochloric acid is added to the treated water to lower the pH to nearly neutral levels. Treated water then passes through a filtration system

that removes any residual suspended solids before discharge. Treated water from the SITE demonstration will be discharged into a uranium disposal pond on site.

Technology Performance

The EPA SITE Program demonstration was conducted during the week of July 26, 1993, at the Palangana Uranium Mine site in Benevides, Texas. A treatability study on disposal pond water from the site had been conducted in 1992.

Remediation Costs

Cost information is not yet available.

General Site Information

The Palangana Uranium Mine site, located in Benevides, Texas, is about 50 miles west of Corpus Christi. The site occupies 161 acres and is surrounded primarily by undeveloped land. It is located in an area known as the South Texas Uranium Province.

In 1968, Union Carbide Corporation, the original owner and operator, began testing on-site leaching of uranium at the site. This process involved injecting chemicals into the ground water aquifer through injection wells. The ground water mixture then was pumped from the aquifer through extraction wells, and the uranium was concentrated through evaporation. Ground water with concentrations of uranium

too low to be of value was transferred to disposal ponds for dilution and eventual use in irrigation. Union Carbide later began commercial operations that included leaching, processing, and distributing uranium.

In 1981, Chevron Resources, Inc., bought the mine and limited its activities to small-scale operations. Active leaching of uranium was discontinued in 1986, and full-scale environmental restoration began. The leaching operations contaminated the disposal ponds with low to moderate levels of NORM which consists of various isotopes of uranium and associated decay products. The NORM detected in the disposal ponds are gross alpha and beta particle-emitting contaminants, uranium, radium-226, and thorium-230.

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Other Physical Treatment

Precipitation, Microfiltration, and Sludge Dewatering Pesticides, Oil, and Grease in Sludge and Leachable Soil

Technology Description

In the first step of this process, heavy metals are chemically precipitated. The precipitates along with all particles down to 0.2 to 0.1 micron, are filtered through a unique fabric cross-flow microfilter (EXXFLOW). The concentrate stream is then dewatered in an automatic tubular filter press of the same fabric material (EXXPRESS).

EXXFLOW microfilter modules are fabricated from a proprietary woven polyester array of tubes. Wastes are pumped into the tubes from a dynamic membrane, which produces a high quality filtrate removing all particle sizes greater than 0.2 - 0.1 micron. The membrane is maintained by the flow velocity, thereby minimizing production declines and cleaning frequencies.

Metals are removed via filtration following precipitation by adjusting the pH in the EXXFLOW feed tank. The metal hydroxides or oxides form the dynamic membrane with all other suspended solids. The concentrate stream will contain up to 5 percent solids for discharge to the EXXPRESS system. The EXXFLOW concentrate stream enters the EXXPRESS modules with the discharge valve closed. A semi-dry cake, up to 1/4 inch thick, is formed on the inside of the tubular cloth. When the discharge valve is opened, rollers on the outside of the tube move to form a venturi within the tube. The venturi creates an area of high velocity within the tubes, which aggressively cleans the cloth and discharges the cake in chip form onto a wedge wire screen. The discharge water is recycled back to the feed tank. The

EXXPRESS filter cakes are typically 40 to 60 percent solids by weight.

Other constituent removals are possible using seeded slurry methods in EXXFLOW. Hardness can be removed by using lime. Oil and grease can be removed by adding adsorbents. Non-volatile organics and solvents can be removed using seeded, powdered activated carbon or powdered ion exchange adsorbents.

In cases where the solids in the raw feed are extremely high, EXXPRESS can be used first, with EXXFLOW acting as a final polish for the product water.

The EXXFLOW/EXXPRESS demonstration unit is transportable and is skid-mounted. The unit is designed to process approximately 30 lbs/hr of solids and 10 gpm of wastewater.

This technology is applicable to water containing heavy metals, pesticides, oil and grease, bacteria, suspended solids, and constituents that can be precipitated into particle sizes greater than 0.1 micron. The system can handle waste streams containing up to 5 percent solids and produce a semi-dry cake of 40 to 60 percent weight per weight. Non-volatile organics and solvents can also be removed from the water by adding powdered adsorbents.

Soils and sludge can be decontaminated through acid leaching of the metals, followed by precipitation and microfiltration. Lime sludges from municipal, industrial, and power plant clarifiers can also be treated by using this process.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1989. Bench-scale tests were conducted in 1990. The first EPA application was acid mine drainage at the Iron Mountain Mine Superfund site in Redding, California, in late 1991.

Since 1988, this technology has been applied to over 40 sites worldwide. System capacities range from 1 gpm to over 2 million gal/day.

Remediation Costs

Cost information was not provided for this publication.

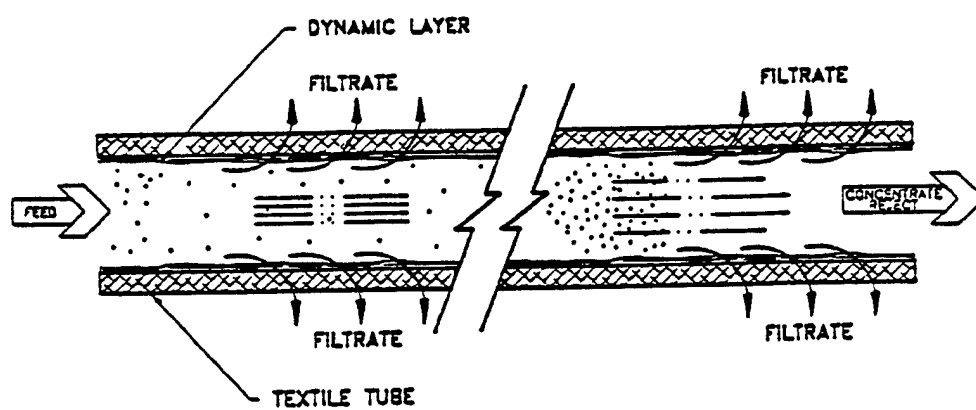
General Site Information

This technology has been applied at a variety of sites, including the Iron Mountain Mine Superfund site in Redding, California. Applications have included acid mine drainage, industrial laundries, circuit board shops, ceramics, agricultural chemicals, oil produced water, oil field waste, scrubber waste, municipal waste, water purification, water softening, clarifier sludge dewatering, and wine and juice filtration.

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Precipitation/Microfiltration System



Other Physical Treatment

Rochem Disc Tube Module System Organics in Aqueous Solutions

Technology Description

This technology uses membrane separation systems to treat a range of aqueous solutions from seawater to leachates containing organics solvents. The system uses osmosis through a semipermeable membrane to separate pure water from contaminated liquids. The application of osmotic theory implies that when a saline solution is separated from pure water by a semipermeable membrane, the higher osmotic pressure of the salt solution will cause the water (and other compounds having high diffusion rates through the selected membrane) to diffuse through the membrane into the salt water. Water will continue to permeate into the salt solution until the osmotic pressure of the salt solution equals the osmotic pressure of the pure water. However, if an external pressure is exerted on the salt solution, water will flow in the reverse direction from the salt solution into the pure water. This phenomenon, known as reverse osmosis, can be employed to separate pure water from contaminated matrices, such as the treatment of hazardous wastes through concentration of hazardous chemical constituents in an aqueous brine, while pure water can be recovered on the other side of the membrane.

Ultrafiltration (UF) is a pressure-driven membrane filtration process that can be used to separate and concentrate macromolecules and colloids from process streams, water, and wastewaters. UF is used in conjunction with reverse osmosis in the Disc Tube Module System. The size of the particle rejected by ultrafiltration depends on the inherent properties of the specific membrane selected for separation

and can range from small particulate matter to large molecules. In general, a fluid is placed under pressure on one side of a perforated membrane having a measured pore size. All materials smaller than the pore pass through, leaving larger contaminants concentrated on the feed side of the process. Control of pass-through constituents can be achieved by using a membrane with a limiting pore size or by installing a series of membranes with successively smaller pores. Although similar to reverse osmosis, the UF process typically cannot separate constituents from water to the level of purity that reverse osmosis can achieve. However, the two technologies can be used in tandem, with UF removing most of the relatively large constituents of a process stream before application of reverse osmosis to selectively remove the water from the remaining mixture.

The fluid dynamics and construction of the system result in an open-channel, fully turbulent feed and water-flow system. This configuration prevents the accumulation of suspended solids on the separation membranes, thereby ensuring high efficiency filtration of water and contaminants. Also, the design of the disc tubes allows for easy cleaning of the filtration medium, providing a long service life for the membrane components of the system.

Waste feed, process permeate, and rinse water are potential feed materials to the reverse osmosis or UF modules, which are skid-mounted and consist of a tank and a high-pressure feed system. The high pressure feed system consists of a centrifugal feed pump, a prefilter cartridge housing, and a triplex plunger pump to feed the

modules. The processing units themselves are self-contained and need only electrical and interconnection process piping to be installed prior to operation.

This system can treat sanitary landfill leachate containing organics and inorganic chemical species, water-soluble oil wastes used in metal fabricating and manufacturing industries, and solvent-water and oil-water mixtures generated during washing operations at metal fabricating facilities.

Technology Performance

The technology was accepted into the EPA SITE Demonstration Program in 1991. A demonstration was conducted in 1992 at Casmalia in Santa Barbara County, California. This site involved the cleanup of leachate from a hazardous waste landfill. During the demonstration, 1 to 2 gpm of contaminated water were processed over a 2- to 3-week period. All feed and residual effluent streams were sampled to evaluate the performance of the technology.

Remediation Costs

Cost information was not provided for this publication.

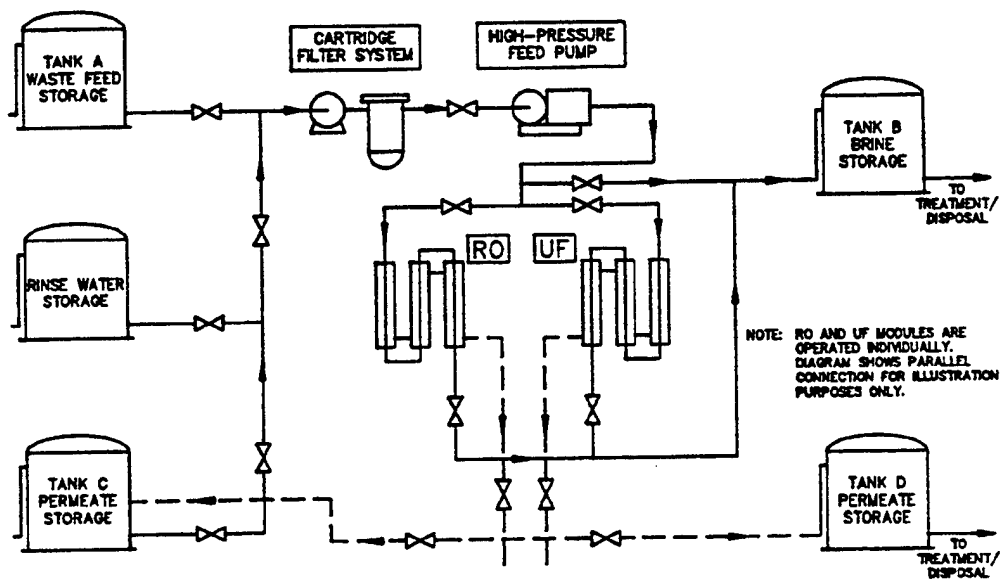
General Site Information

A SITE Program demonstration was conducted at Casmalia in Santa Barbara County, California.

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Rochem Disc Tube Module System



Other Physical Treatment

Selective Extraction Uranium in Soil

Technology Description

This treatment uses physical separation (trommel screens, centrifuge) and chemical extraction (carbonate and citric acid) techniques to remove uranium contaminants from a soil matrix.

The process produces uranium waste and wastewater containing iron and aluminum. The uranium waste is disposed by burial. A possible limitation of this technology is that the secondary waste generated (predominantly iron) may require disposal.

Approximately 10 volumes of treatable wastewater is produced for each volume of soil treated. Existing wastewater technologies should allow the wastewater to be treated and returned to a useable water source.

Technology Performance

This technology is being evaluated as part of DOE's Integrated Technology Demonstration program for Uranium Soils.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

The process is being demonstrated at DOE's Fernald Site. The Fernald Site is located on 1,050 acres near the Great Miami River, 18 miles northwest of Cincinnati, Ohio. Established in the early 1950s, the production complex was used for processing uranium and its compounds from natural uranium ore concentrates. As the primary production site for uranium metal for defense projects in the past, the facility was key to national security.

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Other Physical Treatment

Soil Recycling Organics and Inorganics in Soils

Technology Description

This soil recycling process involves three technologies operating in a series. The process removes inorganic and organic contaminants in soil to produce a reusable fill material. First is a soil washing process that reduces the volume of the material to be treated by concentrating contaminants in a fine slurry mixture. Second, heavy metals are removed from the slurry through a process of metal dissolution. Using acidification and selective chelation, this process recovers all metals in their pure form. Third, a process involving chemical hydrolysis accompanied by biodegradation destroys organic contaminants in the slurry. The three integrated technologies are capable of cleaning contaminated soil for reuse on industrial sites.

Technology Performance

This process was accepted into the EPA SITE Demonstration Program in 1991. It was demonstrated at a site in the Toronto Port Industrial District that had been used for metals finishing and refinery and for petroleum storage. The objective of the demonstration was to evaluate the ability of the process to achieve the modified Ontario Ministry of the Environment (MOE) criteria for commercial and industrial sites. A summary of results follows:

	Feed (mg/kg)	Clean Sand (mg/kg)	Contaminated Fine Slurry (mg/kg)
Oil & grease	0.8	0.2	4
Naphthalene	11	2	52
Benzo(a)pyrene	2	0.5	10

The chemical treatment process and biological soil reactors achieved a 90 percent reduction in simple polycyclic aromatic hydrocarbon compounds such as naphthalene, but slightly exceeded the MOE criteria for benzo(a)pyrene. The results are summarized below:

	Contaminated Fine Slurry (mg/kg)	Treated Fine Slurry (mg/kg)
Naphthalene	52	< 5
Benzo(a)pyrene	10	2.6

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology was demonstrated at a site in the Toronto Port Industrial District in Toronto, Ontario, Canada.

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Other Physical Treatment

Thermal Gas Phase Reduction PCBs, PAHs, Chlorophenols, and Pesticides in Soil, Sludge, Liquids, and Gases

Technology Description

This patented process is based on the gas-phase, thermo-chemical reaction of hydrogen with organic and chlorinated organic compounds at elevated temperatures. At 850°C or higher, hydrogen reacts with organic compounds in a process known as reduction to produce smaller, lighter hydrocarbons. This reaction is enhanced by the presence of water, which can also act as a reducing agent. Because hydrogen is used to produce a reducing atmosphere devoid of free oxygen, the possibility of dioxin or furan formation is eliminated.

The thermo-chemical reaction takes place within a specially designed reactor. In the process, a mixture of preheated waste and hydrogen is injected through nozzles mounted tangentially near the top of the reactor. The mixture swirls around a central ceramic tube past glo-bar heaters. By the time the mixture passes through the ports at the bottom of the ceramic tube, it has been heated to 850°C. Particulate matter up to 5 millimeters in diameter not entrained in the gas stream will impact the hot refractory walls of the reactor. Organic matter associated with the particulate is volatilized, and the particulate exits out of the reactor bottom to a quench tank, while finer particulate entrained in the gas stream flows up the ceramic tube into an exit elbow and through a retention zone. The reduction reaction begins at the bottom of the ceramic tube onwards, and takes less than one second to complete. Gases enter a scrubber where hydrogen chloride fine particulates are removed. The gases that exit the scrubber consist only of

excess hydrogen, methane, and a small amount of water vapor. Approximately 95 percent of this gas is recirculated back into the reactor. The remaining 5 percent is fed to a boiler where it is used as supplementary fuel to preheat the waste.

Because this process is not incineration, the reactor does not require a large volume for the addition of combustion air. The small reactor size and the capability to recirculate gases from the reaction make the process equipment small enough to be mobile.

In addition, the process includes a sophisticated on-line mass spectrometer unit as a part of the control system. As the unit is capable of measuring many organic chemicals on a continuous basis, increases in chlorobenzene or benzene concentrations (signalling a decrease in destruction efficiency) halt the input of waste and alert the operator.

The technology is suitable for many types of waste including PCBs, PAHs, chlorophenols, pesticides, landfill leachates, and lagoon bottoms. The system can handle most types of waste media, including soils, sludges, liquids, and gases. Even those wastes with a high water content are easily handled by the technology.

The developer has built a front-end thermal desorption unit to preheat soils. This increased the overall throughput of the demonstration-scale mobile field unit to 25 tons/day. This unit was demonstrated in 1992.

In the case of chlorinated organic compounds, such as PCBs, the products of the reaction include chloride, hydrogen, methane, and ethylene. Other non-chlorinated hazardous contaminants, such as PAHs, are also reduced to smaller, lighter hydrocarbons, primarily methane and ethylene.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1991. Testing in Hamilton Harbour, Ontario, was completed in 1991 on PAH- and PCB-contaminated harbor sediments. The technology achieved a destruction removal efficiency of 99.9999 percent PCBs in the coal tar sediments.

A demonstration was completed late in 1992. The project was a cooperative effort of U.S. EPA, Eco Logic, Environment Canada, Ontario Ministry of the Environment, Michigan Department of Natural Resources, and the City of Bay City, Michigan. The technology was demonstrated at Middleground Landfill on PCB- and TCE-contaminated leachates and soils.

Remediation Costs

Cost information was not provided for this publication.

General Site Information

This technology was demonstrated at Hamilton Harbour in Ontario, Canada.

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Other Physical Treatment

Ultraviolet Radiation and Oxidation Halogenated Hydrocarbons, VOCs, Pesticides, and PCBS in Ground Water

Technology Description

This ultraviolet (UV) radiation and oxidation process uses UV radiation, ozone (O_3), and hydrogen peroxide (H_2O_2) to destroy toxic organic compounds, particularly chlorinated hydrocarbons, in water. The process oxidizes compounds that are toxic or refractory (resistant to biological oxidation) in concentrations of ppm or ppb.

The system consists of a treatment tank module, an air compressor and ozone generator module, and a hydrogen peroxide feed system. It is skid-mounted and portable, and permits on-site treatment of a wide variety of liquid wastes, such as industrial wastewaters, ground waters, and leachate. The treatment tank size is determined from the expected wastewater flow rate and the necessary hydraulic retention time to treat the contaminated water. The approximate UV intensity, and ozone and hydrogen peroxide doses, are determined from pilot-scale studies.

Influent to the treatment tank is simultaneously exposed to UV radiation, ozone, and hydrogen peroxide to oxidize the organic compounds. Off-gas from the treatment tank passes through an ozone destruction (decompozon) unit, which reduces ozone levels before air venting. The decompozon unit also destroys VOCs stripped off in the treatment tank. Effluent from the treatment tank is tested and analyzed before disposal.

Contaminated ground water, industrial wastewaters, and leachates containing halogenated solvents, phenol, PCP, pesticides, PCBs, and

other organic compounds are suitable for this treatment process.

Technology Performance

A field-scale demonstration was completed in March 1989 at a hazardous waste site in San Jose, California. The test program was designed to evaluate the performance of the Ultrox system at several combinations of five operating parameters: (1) influent pH, (2) retention time, (3) ozone dose, (4) hydrogen peroxide dose, and (5) UV radiation intensity. The Technology Evaluation Report was published in January 1990 (EPA/540/5-89/012). The Applications Analysis Report was published in September 1990 (EPA/540/A5-89/012).

Contaminated ground water treated by the Ultrox system met regulatory standards at the appropriate parameter levels. Out of 44 VOCs in the wastewater, three were chosen to be used as indicator parameters. They are trichloroethylene (TCE), 1,1 dichloroethane (1,1-DCA), and 1,1,1 trichloroethane (1,1,1-TCA), all relatively refractory to conventional oxidation.

Removal efficiencies for TCE were about 99 percent. Removal efficiencies for 1,1-DCA and 1,1,1-TCA were about 58 percent and 85 percent, respectively. Removal efficiencies for total VOCs were about 90 percent.

For some compounds, removal from the water phase resulted from both chemical oxidation and stripping. Stripping accounted for 12 to 75 percent of the total removal for 1,1,1-TCA, and

5 to 44 percent for 1,1-DCA. Stripping was less than 10 percent for TCE and vinyl chloride, and was negligible for other VOCs present.

The decompozon unit reduced ozone to less than 0.1 ppm, with efficiencies greater than 99.99 percent. VOCs present in the air within the treatment system were not detected after passing through the decompozon unit. There were no harmful air emissions to the atmosphere from the system.

Very low total organic carbon removal was found, implying partial oxidation of organics without complete conversion to carbon dioxide and water.

The technology is fully commercial, with over 20 commercial systems installed. Flow rates ranging from 5.0 gpm to 1,050 gpm are presently being used in various industries and site clean-up activities, including aerospace, Department of Energy (DOE), petroleum, pharmaceutical, automotive, wood treating and municipal facilities.

UV oxidation has been included in Records of Decision for several Superfund sites where ground water pump-and-treat remediation methods are to be used.

Remediation Costs

Cost information was not provided for this publication.

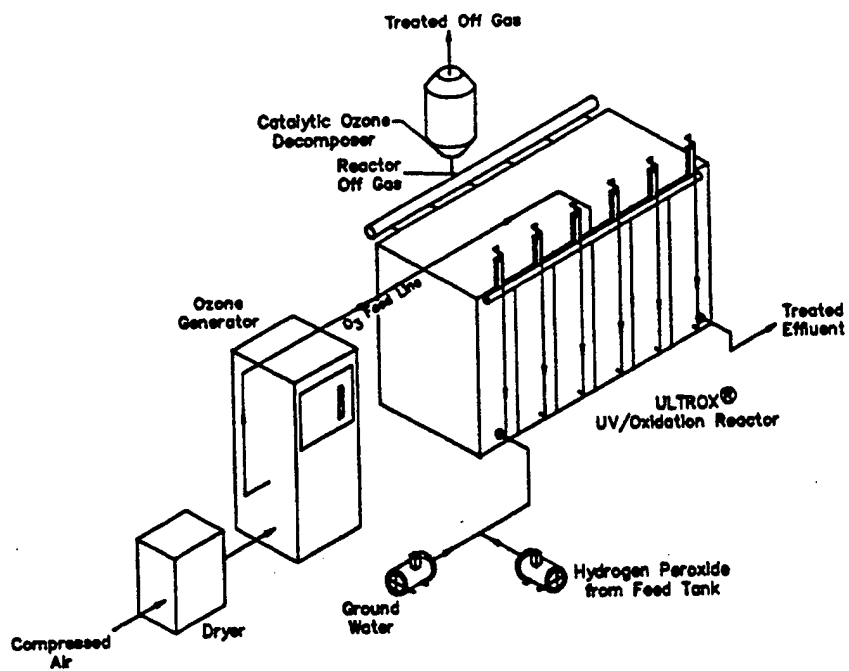
General Site Information

This technology was demonstrated at a hazardous waste site in San Jose, California.

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Ultrox System (Isometric View)



Other Physical Treatment

Ultraviolet Radiation, Hydrogen Peroxide, and Ozone Trichloroethylene in Ground Water

Technology Description

This oxidation process uses ozone, ultraviolet radiation, and hydrogen peroxide for the treatment of ground water contaminated with trichloroethylene (TCE).

Technology Performance

Results from the full-scale, advanced oxidation process tested at the DOE Kansas City plant were mostly inconclusive:

- The plant is effective in the destruction of individual VOCs but seems to reach a plateau for gross parameters such as total organic carbon and total chlorinated hydrocarbons;
- The plant has been out of service for maintenance and repair approximately 30 percent of the time;
- The flow rate has averaged approximately 15 percent of the design flow rate, so the determination of costs has been inconclusive; and
- An evaluation of the true plant capacity indicates that it can accommodate twice the rated flow rate.

Remediation Costs

Actual costs are not available; however, the costs are competitive with other processes.

General Site Information

A full-scale, advanced oxidation process was tested at the DOE Kansas City Plant.

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Other Physical Treatment

Wetlands-Based Treatment Metals in Influent Waters

Technology Description

The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in a man-made wetland ecosystem to accumulate and remove metals from influent waters. The treatment system incorporates principal ecosystem components found in wetlands, including organic soils, microbial fauna, algae, and vascular plants.

Influent waters, which contain high metal concentrations and have a low pH, flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed by filtration, ion exchange, adsorption, absorption, and precipitation through geochemical and microbial oxidation and reduction. In filtration, metal flocculates and metals that are adsorbed onto fine sediment particles settle in quiescent ponds, or are filtered out as the water percolates through the soil or the plant canopy. Ion exchange occurs as metals in the water come into contact with humic or other organic substances in the soil medium. Oxidation and reduction reactions that occur in the aerobic and anaerobic zones, respectively, play a major role in removing metals as hydroxides and sulfides.

The wetlands-based treatment process is suitable for acid mine drainage from metal or coal mining activities. These wastes typically contain high metals concentrations and are acidic in nature. Wetlands treatment has been applied with some success to wastewater in the eastern regions of the United States. The process may have to be adjusted to account for differences in geology, terrain, trace metal composition, and

climate in the metal mining regions of the western United States.

Technology Performance

As a result of the success of this technology in the Emerging Technology Program, it was selected for the EPA SITE Demonstration Program.

The final year of the project under the Emerging Technology Program was 1991. Results of a study of drainage from the Big Five Tunnel near Idaho Springs, Colorado, have shown that by optimizing design parameters, removal efficiency of heavy metals from the discharge can approach the removal efficiency of chemical precipitation treatment plants.

One of the final goals of this project was the development of a manual that discusses design and operating criteria for construction of a full-scale wetland for treating acid mine discharges. The "Wetland Designs for Mining Operations" manual is available from NTIS.

The Demonstration Program will evaluate the effectiveness of a full-scale wetland. The proposed demonstration site is the Burleigh Tunnel near Silver Plume, Colorado. The Burleigh Tunnel is part of the Clear Creek/Central City Superfund Site in Colorado.

Remediation Costs

Cost information was not provided for this publication.

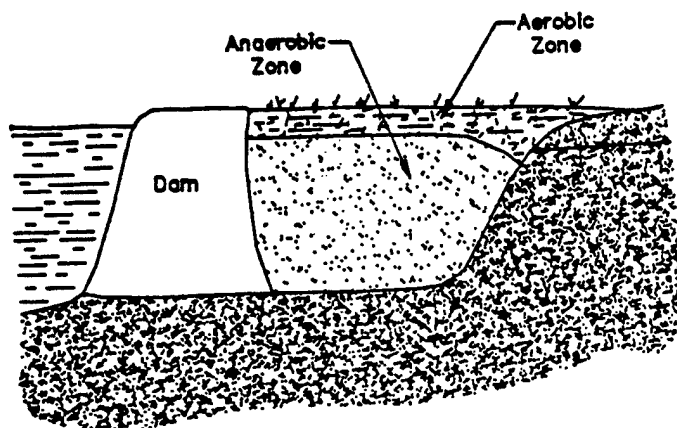
General Site Information

A SITE Program demonstration will be conducted at the Burleigh Tunnel near Silver Plume, Colorado.

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Typical Wetland Ecosystem

APPENDIX A

Incineration and Solidification Demonstrations

Circulating Bed Combustor

Halogenated and Non-Halogenated Organic Compounds and PCBs in Soil, Sludge, and Liquids

Technology Description

The Circulating Bed Combustor (CBC) uses high velocity air to entrain circulating solids and create a highly turbulent combustion zone for the efficient destruction of toxic hydrocarbons. The commercial-size combustion chamber (36 inches in diameter) can treat up to 150 tons of contaminated soil daily, depending on the heating value of the feed material.

The CBC operates at fairly low temperatures (1,450°F to 1,600°F) for this class of technology, thus reducing operating costs and potential emissions such as nitrogen oxides (NO_x) and carbon monoxide. Auxiliary fuel can be natural gas, fuel oil, or diesel. No auxiliary fuel is needed for waste streams having a net heating value greater than 2,900 Btu/lb. The CBC's high turbulence produces a uniform temperature around the combustion chamber and hot cyclone. It also promotes the complete mixing of the waste material during combustion. The effective mixing and relatively low combustion temperature also reduce emissions of carbon monoxide and nitrogen oxides. Hot gases produced during combustion pass through a convective gas cooler and baghouse before being released to the atmosphere.

Waste material and limestone are fed into the combustion chamber along with the recirculating bed material from the hot cyclone. The limestone neutralizes acid gases. The treated ash is transported out of the system by an ash conveyor for proper disposal.

The CBC process may be applied to liquids, slurries, solids, and sludges contaminated with corrosives, cyanides, dioxins/furans, inorganics,

metals, organics, oxidizers, pesticides, PCBs, phenols, and volatiles.

Industrial wastes from refineries, chemical plants, manufacturing site cleanups, and contaminated military sites are amenable to treatment by the CBC process. The CBC is permitted by EPA under the Toxic Substance Control Act (TSCA) to burn PCBs in all ten EPA Regions, having demonstrated a 99.9999 percent destruction removal efficiency (DRE).

Waste feed for the CBC must be sized to less than 1 inch. Metals in the waste do not inhibit performance and become less leachable after incineration. Treated residual ash can be replaced on-site or stabilized for landfill disposal if metals exceed regulatory limits.

Technology Performance

The technology was accepted into the EPA SITE Demonstration Program in March 1989. Ogden Environmental Services (OES) conducted a treatability study and demonstration on wastes obtained from a Superfund site in California (McColl) under the guidance of the SITE program, EPA Region 9, and the California Department of Health Services. The pilot-scale demonstration was conducted by using the 16-inch-diameter CBC at Ogden's Research Facility in San Diego, California.

The EPA SITE program concluded that the test successfully achieved the desired goals, as follows:

- Obtained DRE values of 99.99 percent or greater for principal organic hazardous constituents and minimized the formation of products of incomplete combustion.

- Met the OES Research Facility permit conditions and the California South Coast Basin emission standards.
- Controlled sulfur oxide emissions by adding limestone, and determined that the residual materials (fly ash and bed ash) were nonhazardous. No significant levels of hazardous organic compounds left the system in the stack gas or remained in the bed and fly ash material. The CBC was able to minimize emissions of sulfur oxide, nitrogen oxide, and particulates. Other regulated pollutants were controlled to well below permit levels.

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HRD Flame Reactor

Metals in Wastes and Residues

Technology Description

The HRD Flame Reactor system is a patented, high-temperature thermal process designed to safely treat dry, granular industrial residues and wastes containing metals and organics. The technology processes wastes by subjecting them to a hot (greater than 2,000°C) reducing gas produced by the combustion of solid or gaseous hydrocarbon fuels in oxygen-enriched air. At these temperatures volatile metals in the waste are volatilized and organic compounds are destroyed. The waste materials react rapidly, producing a non-leachable slag (a glass-like solid when cooled) and gases, including steam and volatile metal vapors. The metal vapors further react and cool in the combustion chamber and cooling system to produce a metal-enriched oxide that is collected in a baghouse. The resulting metal oxides can be recycled to recover the metals. The amount of volume reduction to slag and oxide depends on the chemical and physical properties of the waste. Non-volatile metals are vitrified in the slag that leaves the reactor from the slag separator. After testing to ascertain that the slag is non-hazardous, it generally can be recycled as clean fill material. If the slag cannot be recycled because it is determined to be toxic, it can be disposed of in a permitted landfill.

The technology can be applied to granular solids, soil, flue dusts, slags, and sludges containing very high concentrations of heavy metals. In general, the system requires wastes to be dry (less than 15 percent total moisture) and fine-grained (less than 200 mesh) to react rapidly. Larger particles (up to 20 mesh) can be processed but may decrease the efficiency of metals recovery or the capacity of the reactor. Wastes not meeting moisture-content and particle-size criteria require pretreatment.

Generally, wastes with high concentrations of heavy metals that have a significant market value (zinc, lead, arsenic, and possibly silver and gold) should enhance the overall process economics. Product metal oxide containing valuable metals can be processed further for metal recovery in industrial smelters.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1990. Currently, the prototype flame reactor technology system operates with a capacity of 1 to 3 tons/hr in a stationary mode at the developer's facility in Monaca, Pennsylvania. EPA and the developer believe that a mobile system can be designed and constructed for on-site treatment at hazardous waste sites.

The SITE demonstration was conducted in 1991 on secondary lead smelter-soda slag from the National Smelting and Refining Company Superfund site in Atlanta, Georgia. The test was conducted at the Monaca facility under a RCRA research, development, and demonstration permit that allowed the treatment of Superfund wastes containing high concentrations of metals, but only negligible concentrations of organics. The waste material was a granular secondary lead smelter blast furnace soda slag containing arsenic, cadmium, iron, lead, sodium, zinc, and other metals, plus carbon, chlorine, silicon, sulphur, other inorganic chemicals, and water.

A follow-up test with feed containing organics is planned for the near future.

Results from the SITE demonstration are documented in an EPA Applications Analysis

Report (EPA/540/A5-91/005) and a Technology Evaluation Report (EPA/540/5-91/005).

Remediation Costs

The HRD Flame Reactor system processed secondary lead smelter soda slag during the SITE demonstration at an estimated cost of \$932/ton. This cost included extensive testing. Costs for this system are highly site-specific. Variability in waste characteristics and the costs of transporting waste to the reactor, as well as costs of transporting, shipping, and handling residuals, could significantly affect costs.

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Infrared Thermal Destruction Organics in Soil and Sediment

Technology Description

The infrared thermal destruction technology is a mobile thermal processing system that uses electrically powered silicon carbide rods to heat organic wastes to combustion temperatures. Any remaining combustibles are incinerated in an afterburner. One configuration for this mobile system consists of four components: (1) an electric-powered infrared primary chamber, (2) a gas-fired secondary combustion chamber, (3) an emissions control system, and (4) a control center.

Waste is fed into the primary chamber and exposed to infrared radiant heat (up to 1,850°F) provided by silicon carbide rods above the belt. A blower delivers air to selected locations along the belt to control the oxidation rate of the waste feed. The ash material in the primary chamber is quenched by using scrubber water effluent. The ash is then conveyed to the ash hopper, where it is removed to a holding area and analyzed for organic contaminants, such as PCB content.

Volatile gases from the primary chamber flow into the secondary chamber, which uses higher temperatures, greater residence time, turbulence, and supplemental energy (if required) to destroy these gases. Gases from the secondary chamber are vented through the emissions control system. In the emissions control system, the particulates are removed in a venturi scrubber. Acid vapor is neutralized in a packed tower scrubber. An induced draft blower draws the cleaned gases from the scrubber into the free-standing exhaust stack. The scrubber liquid effluent flows into a clarifier where scrubber sludge settles out for disposal. The liquid then flows through an

activated carbon filter for reuse or to a publicly owned treatment works (POTW) for disposal.

This technology is suitable for soils or sediments with organic contaminants. Liquid organic wastes can be treated after mixing with sand or soil. Optimal waste characteristics are as follows:

- Particle size, 5 microns to 2 inches.
- Moisture content, up to 50 percent by weight.
- Density, 30 to 130 lbs/ft³.
- Heating value, up to 10,000 Btu/lb.
- Chlorine content, up to 5 percent by weight.
- Sulfur content, up to 5 percent by weight.
- Phosphorus, 0 to 300 ppm.
- pH, 5 to 9.
- Alkali metals, up to 1 percent by weight.

Technology Performance

EPA conducted two SITE Program demonstrations of the infrared system. An evaluation of a full-scale unit was conducted during August, 1987 at the Peak Oil site in Tampa, Florida. The system treated nearly 7,000 yd³ of waste oil sludge containing PCBs and lead. A second pilot-scale demonstration took place at the Rose Township/Demodé Road Superfund site in Michigan during November, 1987. Organics, PCBs, and metals in soil were the target waste compounds to be immobilized. In addition, the technology has been used to remediate PCB contamination at the Florida Steel Corporation and the LaSalle Electric Superfund sites. The results from the two SITE demonstrations are summarized below.

- PCBs were reduced to less than 1 ppm in the ash, with a destruction removal efficiency (DRE) for air emissions greater than 99.99 percent (based on detection limits).
- In the pilot-scale demonstration, the RCRA standard for particulate emissions (180 mg/dry standard m³) was achieved. In the full-scale demonstration, however, this standard was not met in all runs because of scrubber inefficiencies.
- Lead was not immobilized; however, it remained in the ash, and significant amounts were not transferred to the scrubber water or emitted to the atmosphere.
- The pilot testing demonstrated satisfactory performance with high feed rate and reduced power consumption when fuel oil was added to the waste feed and the primary chamber temperature was reduced.

Results from these demonstrations have been published by EPA in the two Applications Analysis Reports (EPA/540/A5-89/010 and EPA/540/A5-89/007) and two Technology Evaluation Reports (EPA/540/5-88/002a and EPA/540/5-89/007a).

Results from the two demonstrations, plus eight other case studies, indicate the process is capable of meeting both RCRA and TSCA DRE requirements for air emissions and particulate emissions. Restrictions in chloride levels in the feed waste may be necessary. PCB remediation has consistently met the TSCA guidance level of 2 ppm in ash.

This technology is no longer available through vendors in the United States.

Remediation Costs

Economic analysis suggests an overall waste remediation cost up to \$800/ton.

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PYRETRON® Thermal Destruction

Organics in Soil, Sludge, and Solid Waste

Technology Description

The PYRETRON® thermal destruction technology is an integrated combustion system. It controls the heat input into the incineration process by using the PYRETRON® oxygen-air-fuel burners and the dynamic control of the level of excess oxygen available for oxidation of hazardous waste. The PYRETRON® combustor uses an advanced combustion concept that relies on a new technique for mixing auxiliary fuel, oxygen, and air in order to (1) provide the flame envelope with enhanced stability, luminosity, and flame core temperature and (2) provide a reduction in the combustion volume per million Btu of heat released.

The system is computer controlled to automatically adjust the temperatures of the primary and secondary combustion chambers and the amount of excess oxygen being supplied to the combustion process. The system has been designed to dynamically adjust the amount of excess oxygen in response to sudden changes in the rate of volatilization of contaminants from the waste.

The burner system can be fitted onto any conventional incineration unit and used for the burning of liquids, solids, and sludges. Solids and sludges can also be co-incinerated when the burner is used in conjunction with a rotary kiln or similar equipment.

High and low Btu solid wastes contaminated with rapidly volatilized hazardous organics are suitable for the PYRETRON® technology. In general, the technology is applicable to any waste that can be incinerated. The technology is not suitable for processing aqueous wastes, RCRA heavy metal wastes, or inorganic wastes.

Technology Performance

An EPA SITE Program demonstration was conducted at EPA's Combustion Research Facility in Jefferson, Arkansas, using a mixture of 40 percent contaminated soil from the Stringfellow Acid Pit Superfund site in California and 60 percent decanter tank tar sludge from coking operations (RCRA-listed waste K087). The demonstration began in November 1987 and was completed at the end of January 1988.

Both the Technology Evaluation Report (EPA/540/5-89/008) and Applications Analysis Report (EPA/540/A5-89/008) have been published.

Six PAHs—naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, and fluoranthene—were selected as the principal organic hazardous constituents (POHC) for the test program.

The PYRETRON® technology achieved greater than 99.99 percent destruction and removal efficiencies (DRE) of all POHCs measured in all test runs. Other advantages are listed below:

- The PYRETRON® technology with oxygen enhancement achieved double the waste throughput possible with conventional incineration.
- All particulate emission levels in the scrubber system discharge were significantly below the hazardous waste incinerator performance standard of 180 mg/dry standard m³ at 7 percent oxygen.
- Solid residues were contaminant-free.

- There were no significant differences in transient carbon monoxide level emissions between air-only incineration and PYRETRON® oxygen-enhanced operation with doubled throughput rate.
- Costs savings can be achieved in many situations.
- The system is capable of doubling the capacity of a conventional rotary kiln incinerator. This increase is more significant for wastes with low heating values.

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Chemfix Process

Solid Waste in Soil and Sludge

Technology Description

This solidification and stabilization process is an inorganic system in which soluble silicates and silicate-setting agents react with polyvalent metal ions and other waste components to produce a chemically and physically stable solid material. The treated waste matrix displays good stability, a high melting point, and a friable texture. The treated matrix may be similar to soil, depending upon the water content of the feed waste.

The feed waste is first blended in the reaction vessel with dry alumina, calcium, and silica based reagents that are dispersed and dissolved throughout the aqueous phase. The reagents react with polyvalent ions in the waste and form inorganic polymer chains (insoluble metal silicates) throughout the aqueous phase. These polymer chains physically entrap the organic colloids within the microstructure of the product matrix. The water-soluble silicates then react with complex ions in the presence of a silicate setting agent, producing amorphous, colloidal silicates (gels) and silicon dioxide, which acts as a precipitating agent.

Most of the heavy metals in the waste become part of the silicate gel. Some of the heavy metals precipitate with the structure of the silicate gel.

Since some organics may be contained in particles larger than the silicate gel, all of the waste is pumped through processing equipment, creating sufficient shear in combination with surface active chemicals to emulsify the organic constituents. Emulsified organics are then encapsulated and solidified and discharged to a

prepared area where the gel continues to set and stabilize. The resulting solids, though friable, microencapsulate any organic substances that may have escaped emulsification. The system can be operated at 10 to 100 percent solids in the waste feed; water is added to drier wastes. Portions of the water contained in the wastes are involved in three reactions after treatment: (1) hydration, similar to that of cement reactions; (2) hydrolysis reactions; and (3) equilibration through evaporation. There are no side streams or discharges from this process.

This technology is suitable for contaminated soils, sludges, and other solid wastes. The process is applicable to electroplating wastes, electric arc furnace dust, and municipal sewage sludge containing heavy metals such as aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc.

Technology Performance

The technology was demonstrated in March 1989 at the Portable Equipment Salvage Co., site in Clackamas, Oregon. Preliminary results are available in a Demonstration Bulletin (October 1989). The Technology Evaluation Report (TER) was published in September 1990 (EPA/540/5-89/011a). The Applications Analysis Report (AAR) was completed in May 1991 (EPA/540/A5-89/011). Following is a summary of the SITE demonstration:

- The Chemfix Technology was effective in reducing the concentrations of copper and lead in the TCLP extracts. The

concentrations in the extracts from the treated wastes were 94 to 99 percent less than those from the untreated wastes. Total lead concentrations of the untreated waste approached 14 percent.

- The volume of the excavated waste material increase ranged from 20 to 50 percent.
- In the durability tests, the treated wastes showed little or no weight loss after 12 cycles of wetting and drying or freezing and thawing.

- The unconfined compressive strength (UCS) of the wastes varied between 27 and 307 lbs/in² after 28 days. Hydraulic conductivity decreased by more than one order of magnitude.
- The air monitoring data suggest there was no significant volatilization of PCBs during the treatment process.
- The cost of the treatment process was \$73/ton of raw waste treated, exclusive of excavation, pretreatment, and disposal.

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***In Situ* Solidification and Stabilization**
Metals and SVOCs in Soils

Technology Description

The soil-cement mixing wall (SMW) technology involves the *in situ* fixation, solidification, and stabilization of contaminated soils. The technology has been used for more than 18 years to mix soil, cement, and chemical grout for various construction applications including cutoff walls and soil stabilization. Multi-axis overlapping hollow-stem augers are used to inject solidification and stabilization agents into contaminated soils *in situ*. The agents are then blended into the soils. The augers are mounted on a crawler-type base machine. A batch mixing plant and raw materials storage tanks also are used. This system can treat 90 to 140 yds³ of soil in 8 hours at depths of up to 100 ft below ground surface.

The SMW technology produces a monolithic block that extends down to the treatment depth. The volume increase ranges from 10 to 30 percent, depending on the nature of the soil matrix and the amount of reagents and water required for treatment.

This technology can be applied to soils contaminated with metals and semivolatile organic compounds such as pesticides, PCBs, phenols, and PAHs.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in 1989. Site selection is underway.

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***In Situ* Solidification/Stabilization Process**
Inorganic and Organic Compounds in Soil, Sediment, and Sludge

Technology Description

This *in situ* solidification and stabilization technology immobilizes organic and inorganic compounds in wet or dry soils, using reagents (additives) to produce a cement-like mass. The basic components of this technology are: (1) Geo-Con's deep soil mixing system (DSM), a system to deliver and mix the chemicals with the soil *in situ*; and (2) a batch mixing plant to supply the International Waste Technologies' (IWT) proprietary treatment chemicals.

The proprietary additives generate a complex, crystalline, connective network of inorganic polymers. The structural bonding in the polymers is mainly covalent. The process involves a two-phased reaction in which the contaminants are first complexed in a fast acting reaction, and then in a slow acting reaction.

The DSM system involves mechanical mixing and injection. The system consists of one set of cutting blades and two sets of mixing blades attached to a vertical drive auger, which rotates at approximately 15 rpm. Two conduits in the auger are used to inject the additive slurry and supplemental water. Additive injection occurs on the downstroke; further mixing takes place upon auger withdrawal. The treated soil columns are 36 inches in diameter, and are positioned in an overlapping pattern of alternating primary and secondary soil columns.

The technology can be applied to soils, sediments, and sludge-pond bottoms contaminated with organic compounds and metals. The technology has been laboratory tested on soils containing PCBs, PCP, refinery wastes, and chlorinated and nitrated hydrocarbons. The soil mixing technology can treat

any waste for which a physical or chemical reagent is applicable.

Technology Performance

An EPA SITE Program demonstration was conducted at a PCB-contaminated site in Hialeah, Florida, in April 1988. Two 10-by-20-foot test sectors of the site were treated — one to a depth of 18 feet, and the other to a depth of 14 feet. Ten months after the demonstration, long-term monitoring tests were performed on the treated sectors. The Technology Evaluation Report (EPA/540/5-89/004a) and Applications Analysis Report (EPA/540/A5-89/004) have been published.

Key findings from the demonstration are summarized below:

- Immobilization of PCBs appears likely, but could not be confirmed because of low PCB concentrations in the untreated soil. Leachate tests on treated and untreated soil samples showed mostly undetectable PCB levels. Leachate tests performed one year later on treated soil samples showed no increase in PCB concentrations, indicating immobilization.
- Sufficient data were not available to evaluate the performance of the system with regard to metals or other organic compounds.
- Each of the test samples showed high unconfined compressive strength, low permeability, and low porosity. These physical properties improved when retested one year later, indicating the potential for long-term durability.

- The bulk density of the soil increased 21 percent after treatment. This increased the volume of treated soil by 8.5 percent and caused a small ground rise of one inch per treated foot of soil.
- The unconfined compressive strength (UCS) of treated soil was satisfactory, with values up to 1,500 psi.
- The permeability of the treated soil was satisfactory, decreasing four orders of magnitude compared to the untreated soil, or 10^{-6} and 10^{-7} compared to 10^{-2} cm/sec.
- The wet and dry weathering test on treated soil was satisfactory. The freeze and dry weathering test of treated soil was unsatisfactory.
- The microstructural analysis, scanning electron microscopy (SEM), optical microscopy, and x-ray diffraction (XRD), showed that the treated material was dense and homogeneously mixed.
- Data provided by IWT indicate some immobilization of volatile and semivolatile organics. This may be due to organophilic clays present in the IWT reagent. There are insufficient data to confirm this immobilization.
- Performance data are limited outside of SITE demonstrations. The developer modifies the binding agent for different wastes. Treatability studies should be performed for specific wastes.

The process was used to remediate the PCB-contaminated site in Hialeah, Florida, during 1990.

Remediation Costs

Costs for this process are estimated at \$194/ton for the 1-auger machine used in the demonstration and \$111/ton for a commercial 4-auger operation.

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NOMIX® Technology Metals in Waste Lagoons and Spills

Technology Description

The NOMIX® technology is a patented solidification and stabilization process that can be applied to contaminated media *in situ*, without the need for mixing or equipment. The technology combines specially formulated cementitious materials with waste media. Because the material hardens faster than conventional concrete, there is a savings in remediation time.

The NOMIX® solidification compounds consist of specially formulated cements, sands, aggregates, and various combinations thereof. The dry components and their reacting rates with the wet waste are closely controlled, allowing rapid and efficient solidification. The contaminated media may be diluted with water, if necessary, to facilitate the solidification process. If the addition of water is necessary, it may be introduced into the waste media before the addition of the preblended solidification compounds to create a homogenous solution of waste and water. The solidification compounds are then poured through the waste and water solution in a consistent manner, allowing the complete absorption of the waste solution and the formation of a solid mass. The process produces a relatively homogenous treated mass compared to that produced by solidification processes using mixing equipment.

Applications of the technology require little labor because mixing is accomplished simply by pouring the solidification compounds through the waste combination. Greater quantities of waste can be solidified by this process than with normal concrete mixtures because the premixed dry compounds are more absorbent. The

permeability of the treated waste can be controlled by adjusting the mixture's formula.

The process can address contaminated waste contained in drums (or other containers), a minor spill, or even a lagoon. Each of these situations will require its own particular installation procedures. After solidification, the units can be moved for storage, or left in place. The solidified mass may be encased for extra protection with a non-shrink, structural concrete, or a high quality waterproof coating.

The NOMIX® technology is currently most suitable for solidification and stabilization of aqueous wastes in the following situations:

- Solidification of drum waste;
- Solidification of minor spills *in situ* to minimize soil, facility, or plant contamination; and
- Solidification of waste lagoons for long-term, in-place storage, or for solidification in preparation for removal.

The technology has been applied to solutions of arsenic trioxide, barium bromide, cadmium acetate, mercuric chloride, potassium chromate, selenium dioxide, silver nitrate, and zinc sulfate, among others. Hardened masses of each waste were subjected to TCLP analysis as well as American Society of Testing and Materials (ASTM Standard C-109) compressive tests. In all cases, the technology significantly reduced the leachability of each waste stream and achieved compressive strengths of a few hundred psi.

As the technology is improved it will become suitable for solidification of various wastes in soils including inorganic wastes.

Technology Performance

Solidification and stabilization using the NOMIX® Technology was accepted into the EPA SITE Demonstration Program in March 1991. The date and place of the demonstration are undetermined.

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**Solidification of Spent Blasting
Heavy Metals in Spent Blasting Abrasives, Grit, and Sands**

Technology Description

The goal of this technology is to recycle spent abrasives into non-hazardous product that can be reused as a valuable commercial product available for unrestricted public use. In this process, abrasives are screened and mixed with asphalt and other aggregates. Less than one percent inert debris (wood and metal scrap) is produced, although treatment capacity varies with the plant. Target contaminants are lead and copper.

Technology Performance

A field demonstration of this technology was conducted at the Naval Construction Battalion Center at Port Hueneme, California, from February 1991 through February 1992. The test involved 1,200 tons of blasting paint from vehicles.

Remediation Costs

Costs for use of this process are estimated at \$85/ton of waste. Approximately two months are required for design.

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Solidification/Stabilization Organics and Inorganics in Soil, Sludge, and Liquid

Technology Description

This solidification and stabilization technology applies proprietary bonding agents to soils, sludge, and liquid wastes with organic and inorganic contaminants to treat the pollutants within the wastes. The waste and reagent mixture is then mixed with cementitious materials, which form a stabilizing matrix. The specific reagents used are selected based on the particular waste to be treated. The resultant material is a non-leaching, high-strength monolith.

The process uses standard engineering and construction equipment. Since the type and dose of reagents depend on waste characteristics and treatability studies, site investigations must be conducted to determine the proper treatment formula.

The process begins with excavation of the waste. Materials containing large pieces of debris must be prescreened. The waste is then placed into a high shear mixer, along with premeasured quantities of water and SuperSet® (WASTECH's proprietary reagent).

Next, pozzolanic, cementitious materials are added to the waste-reagent mixture, stabilizing the waste and completing the treatment process. WASTECH's treatment technology does not generate waste by-products. The process can also be applied *in situ*.

WASTECH's technology can treat a wide variety of waste streams consisting of soils, sludges, and raw organic streams, such as lubricating oil, aromatic solvents, evaporator bottoms, chelating agents, and ion exchange resins, with contaminant concentrations ranging from ppm levels to 40 percent by volume. The

technology can also treat wastes generated by the petroleum, chemical, pesticide, and wood-preserving industries, as well as wastes generated by many other manufacturing and industrial processes. WASTECH's technology can also be applied to mixed wastes containing radioactive materials, along with organic and inorganic contaminants.

Technology Performance

This technology was accepted into the EPA SITE Demonstration Program in spring of 1989. Bench-scale evaluation of the process is complete, and a field demonstration at Robins Air Force Base in Macon, Georgia, was completed in August 1991. The WASTECH technology was used to treat high-level organic and inorganic wastes at an industrial sludge pit. An abbreviated demonstration with a detailed mass balance evaluation was completed in 1992. The technology is being commercially applied to treat hazardous wastes contaminated with various organics, inorganics, and mixed wastes.

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Solidification/Stabilization with Silicate Compounds

Organics and Inorganics in Ground Water, Soil, and Sludge

Technology Description

This technology for treating hazardous waste utilizes silicate compounds to solidify and stabilize organic and inorganic constituents in contaminated soils, sludges, and wastewater.

The organic chemical fixation/solidification technology involves the bonding of the organic contaminants into the layers of an aluminosilicate compound. The technology involves the formation of insoluble chemical compounds which reduces the overall reagent addition compared to generic cementitious processes.

Pretreatment of contaminated soil includes separation of coarse and fine waste materials, and the crushing of coarse material, reducing it to the size required for the solidification and stabilization technology. The screened waste is weighed and a predetermined amount of silicate reagent is added. The material is conveyed to a pug mill mixer where water is added and the mixture is blended.

Sludges are placed directly into the pug mill for addition of reagents and mixing. The amount of reagent required for solidification and stabilization can be adjusted according to variations in organic and inorganic contaminant concentrations determined during treatability testing. Treated material is placed in confining pits for on-site curing or cast into molds for transport and disposal off site.

This technology has been successfully implemented on inorganic and organic contaminated hazardous remediation projects, inorganic and organic industrial wastewater treatment systems, industrial in-process treatment, and RCRA land ban treatment of F006 and K061 wastes.

The technology can be applied to a wide variety of hazardous soils, sludges, and wastewaters. Applicable waste media include the following:

- Inorganic-contaminated soils and sludges. Contaminants including most metals, cyanides, fluorides, arsenates, chromates, and selenium.
- Organic-contaminated soils and sludges. Organic compounds including halogenated aromatics, PAHs, and aliphatic compounds.
- Inorganic- and organic-contaminated wastewaters. Heavy metals, emulsified and dissolved organic compounds in ground water and industrial wastewater, excluding low-molecular-weight organic contaminants such as alcohols, ketones, and glycols.

Technology Performance

Under the EPA SITE Demonstration Program, the technology was demonstrated in November 1990 at the Selma Pressure Treating (SPT) wood preserving site in Selma, California. The SPT site was contaminated with both organics, mainly PCP, and inorganics, mainly arsenic, chromium and copper. The Applications Analysis Report and Technology Evaluation Report is expected to be published in 1993.

Following is a summary of the results of the demonstration:

- The technology can treat PCP. Extract and leachate concentrations of PCP were reduced by up to 97 percent.
- The technology can immobilize arsenic. TCLP and TCLP-distilled water leachate concentrations were reduced by up to 92 and 98 percent, respectively.
- The technology can immobilize chromium and copper. Initially low TCLP and TCLP-

distilled water leachate concentrations of chromium (0.07 to 0.27 ppm) were reduced up to 54 percent. Initial TCLP and TCLP-distilled water leachate concentrations of copper (0.4 ppm and 9.4 ppm) were reduced up to 99 and 90 percent, respectively.

- Treatment of the wastes resulted in volume increases ranging from 59 to 75 percent (68 percent average).
- After a 28-day curing period, the treated wastes exhibited moderately high unconfined compressive strengths of 260 to 350 psi.
- Permeability of the treated waste was low (approximately 1.7×10^{-7} cm/sec). The relative cumulative weight loss after 12 wet and dry and 12 freeze and thaw cycles was negligible (less than 1 percent).

Remediation Costs

This technology is expected to cost approximately \$200/yd³ when used to treat large amounts (15,000 yds³) of waste similar to that found at the SPT demonstration site.

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Soliditech Solidification/Stabilization Process
Organic and Inorganic Compounds, Metals, Ore and
Grease in Soil and Sludge

Technology Description

This solidification and stabilization process immobilizes contaminants in soils and sludges by binding them in a concrete-like, leach-resistant matrix.

Contaminated waste materials are collected, screened to remove oversized material, and introduced to the batch mixer where it is mixed with (1) water, (2) Urrichem — a proprietary chemical reagent, (3) proprietary additives, and (4) pozzolanic material (fly ash), kiln dust, or cement. After it is thoroughly mixed, the treated waste is discharged from the mixer. Treated waste is a solidified mass with significant unconfined compressive strength, high stability, and a rigid texture similar to that of concrete.

This technology is intended for treating soils and sludges contaminated with organic compounds, metals, inorganic compounds, and oil and grease. Batch mixers of various capacities are available to treat different volumes of waste.

Technology Performance

The process was demonstrated in December 1988 at the Imperial Oil Company/Champion Chemical Company Superfund site in Morganville, New Jersey. This location formerly contained both chemical processing and oil reclamation facilities. Wastes treated during the demonstration were soils, filter cake, and oily wastes from an old storage tank. These wastes were contaminated with petroleum hydrocarbons, PCBs, other organic chemicals, and heavy metals.

Key findings from the Soliditech demonstration are summarized below:

- Chemical analyses of extracts and leachates showed that heavy metals present in the untreated waste were immobilized.
- The process solidified both solid and liquid wastes with high organic content (up to 17 percent), as well as oil and grease.
- Volatile organic compounds in the original waste were not detected in the treated waste.
- Physical test results of the solidified waste samples showed: (1) unconfined compressive strengths ranging from 390 to 860 psi; (2) very little weight loss after 12 cycles of wet and dry and freeze and thaw durability tests; (3) low permeability of the treated waste; and (4) increased density after treatment.
- The solidified waste increased in volume by an average of 22 percent. Because of solidification, the bulk density of the waste material increased by about 35 percent.
- Semivolatile organic compounds (phenols) were detected in the treated waste and the TCLP extracts from the treated waste, but not in the untreated waste or its TCLP extracts. The presence of these compounds is believed to result from chemical reactions in the waste treatment mixture.
- Oil and grease content of the untreated waste ranged from 2.8 to 17.3 percent (28,000 to 173,000 ppm). Oil and grease content of the TCLP extracts of the solidified waste ranged from 2.4 to 12 ppm.
- The pH of the solidified waste ranged from 11.7 to 12.0. The pH of the untreated waste ranged from 3.4 to 7.9.

- PCBs were not detected in any extracts or leachates of the treated waste.
- Visual observation of solidified waste contained dark inclusions about 1 millimeter in diameter. Ongoing microstructural studies are expected to confirm that these inclusions are encapsulated wastes.

A Technology Evaluation Report was published in February 1990 in two volumes. Volume I (EPA/540/5-89/005A) is the report; Volume II (EPA/540/5-89/005B) contains data to supplement the report. An Applications Analysis Report was published in September 1990 (EPA/4540/A5-89/005).

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Stabilization of Small Arms Range Soils Lead in Soil

Technology Description

In this process, contaminated soil is treated *ex situ*. The soil is removed and screened to remove bullets and other debris. Bullets screened out in this phase of the treatment are recycled; other debris is disposed of in a landfill.

Screened soil is mixed with sodium silicate, portland cement, and water. The mixture is then cured, and treated soil is returned to its original location.

Target contaminants for this technology are heavy metals, particularly lead. The goal of the process is to reduce levels of lead to less than EPA criteria.

Technology Performance

A field demonstration of this process was conducted in 1990 at the Small Arms Range at the Naval Air Station Mayport in Florida. Approximately 170 yd³ of contaminated soil was successfully treated in the demonstration. TCLP levels of lead, copper, and zinc were reduced — from 720 ppm to less than 0.9 ppm for lead; from 7 ppm to less than 0.2 ppm for copper; and from 4.1 ppm to less than 0.2 ppm for zinc.

Remediation Costs

Estimated cost for use of this technology was \$490/ton of waste.

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Stabilization with Lime

Hydrocarbons and Organics in Sludge

Technology Description

This technology uses lime to stabilize acidic sludge containing at least five percent hydrocarbons (typical of sludge produced by recycling lubricating oils). The technology can also stabilize waste containing up to 80 percent organics. The process tolerates low levels of mercury and moderate levels of lead and other toxic metals. No hazardous materials are used in the process. The lime and other chemicals are specially prepared to significantly improve their reactivity and other key characteristics.

Sludge is removed from a waste pit using conventional earthmoving equipment and mixed with lime in a separate blending pit. The temperature of the material in the blending pit rises for a brief time to about 100°C, creating some steam. After 20 minutes, almost all of the material is fixed, however, the chemicals mixed in the sludge continue to react with the waste for days. The volume of the waste is increased by 30 percent by adding lime.

The fixed material is stored in a product pile until the waste pit has been cleaned. The waste is then returned to the pit and compacted to a permeability of 10^{-10} cm/sec.

Technology Performance

A SITE Program demonstration is planned for the fall of 1993 or spring of 1994.

Remediation Costs

Cost information is not yet available.

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APPENDIX B

General Technology Development Programs

Bioventing Initiative

In May 1992, the U.S. Air Force launched an extensive program to examine bioventing as a remedial technique at contaminated sites across the country. Bioventing promotes aerobic degradation of hydrocarbons in soil by direct injection or vacuum extraction of air.

The Air Force Bioventing Initiative targets 138 sites with diesel fuel, jet fuel, or fuel oil in soil. In selecting sites for the initiative, the Air Force looked for characteristics appropriate for bioventing, such as deep vadose soil, heavy hydrocarbon contamination, and high air permeability. The chosen sites represent a wide range of depths to ground water, hydrocarbon concentrations, and soil textures.

Short-term testing began at several sites in May to determine the air permeability and *in situ* respiration of the soil. At most sites, the test system consists of a single vent well with screening in the unsaturated zone and three soil-gas monitoring wells at various distances from the vent well. By injecting air through the vent well and measuring the pressure changes in the soil-gas monitoring wells, the soil's air permeability and the radius of influence of the injection well can be determined. The rate of biodegradation in the soil is then determined by temporarily shutting down air injection to the vent well and measuring the rate of *in situ* oxygen respiration in the monitoring wells.

Where short-term tests reveal adequate air permeability and degradation rates, the Air Force initiates long-term bioventing tests. The requisite apparatus and an operation manual are provided to each facility so that base personnel can monitor the progress of long-term testing for two to three years.

At small sites, long-term testing may well complete the necessary remediation. At large sites, data from long-term testing will be used to design full-scale bioventing systems. By January 1993, preliminary testing had been completed and 33 systems had been installed at 15 Air Force Bases (AFBs) and Air National Guard Bases (ANGBs). Initial results were very promising, with degradation rates measured as high as 5,000 mg/kg/year.

The Air Force's decision to examine bioventing on such a large scale was prompted by a successful demonstration of the technology at Tyndall AFB, Florida. At this site, bioventing was coupled with moisture addition to remediate jet fuel in sandy vadose-zone soil. Before bioventing was initiated, hydrocarbon concentrations ranged from 30 to 23,000 mg/kg. After seven months of treatment, one-third of the total petroleum hydrocarbons (TPH) and nearly all of the benzene, toluene, ethylbenzene, and xylene (BTEX) had been removed. Similar projects have been undertaken in cooperation with the U.S. EPA's Bioremediation Field Initiative at Hill AFB, Utah, and Eielson AFB, Alaska.

The Tyndall AFB project demonstrated several advantages of bioventing over alternative oxygen delivery systems. First, bioventing uses low-pressure air flow, so vapor phase hydrocarbons that are volatilized during the venting process are biodegraded before they escape from the soil. This eliminates the need for expensive off-gas treatment and can reduce the cost of remediation significantly. Second, bioventing appears to be the only cost-effective, *in situ* technique for remediating non-volatile and low-volatility hydrocarbons like fuel oil and

diesel. Third, bioventing can be used to treat contaminants in areas where structures and activities cannot be disturbed, because air injection wells, air blowers, and soil-gas monitoring wells for a relatively non-invasive apparatus.

General Site Information

There are more than 4,300 documented Air Force disposal sites requiring investigation and possible remediation. At least half of these sites are contaminated with petroleum hydrocarbons. Depending on site-specific conditions, bioventing could be potentially applicable at these sites.

Under the Bioventing Initiative, bioventing demonstrations have begun at the following Air Force installations: Beale AFB, California; Eglin AFB, Florida; Eielson AFB, Alaska; F.E. Warren AFB, Wyoming; Galena AFB, Alaska; Hanscom AFB, Massachusetts; Hill AFB, Utah; K.I. Sawyer, Michigan; McGuire AFB, New Jersey; Newark Air Force Station, Ohio; Offutt AFB, Nebraska; Plattsburgh AFB, New York; Robins AFB, Georgia; Vandenberg AFB, California; Westover AFB, Massachusetts; and Battle Creek ANGB, Michigan.

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Mixed Waste Landfill

The mission of the Mixed-Waste Landfill Integrated Demonstration (MWLID) is to assess, demonstrate, and transfer technologies and systems that lead to faster, better, cheaper, and safer *in situ* characterization, remediation, and containment of landfills in arid environments that contain heavy metals in complex mixtures with organic, inorganic, and radioactive wastes. The approach involves the use of non- or minimally intrusive characterization technologies, removal of the most mobile contaminants that are of most concern to the regulatory community, and use of verifiable containment methods for the isolation of the remaining constituents. The approach promises to minimize risk to the public and site workers with a significant cost savings. Beyond the development and demonstration of these technologies and systems, there is a strong focus on their transfer to users in both DOE and the commercial sector. MWLID is receiving information from local, state, and federal regulatory agencies, as well as commercial firms and public interest groups on the impacts these technologies are having.

General Site Information

MWLID is demonstrating technologies at three sites. The Chemical Waste Landfill and the Mixed Waste Landfill are located at Sandia National Laboratories, Albuquerque, New Mexico. The other site is the RB-11 mixed waste landfill at Kirtland Air Force Base (KAFB), New Mexico. The KAFB site illustrates DOE's commitment to the transfer of technologies to non-DOE customers.

The characterization technology assessments are focused on pre-screening, drilling, field laboratory, and borehole technologies. Pre-screening encompasses geostatistical routines in the software package for borehole optimization. Drilling applications involve directional, subsurface access. The field laboratory uses field deployable analytical methods for the screening and minimization of environmental sampling. Borehole technologies include flexible membrane liners and downhole sensors.

The focus of remediation efforts is on the removal of the most rapidly moving constituents and isolation of the remaining constituents on either an interim (<30 years) or permanent basis. An integration of existing technologies is being performed for removal of VOCs by a Thermally Enhanced Vapor Extraction System (TEVES), using resistance and radio frequency (RF) heating in combination with vacuum vapor extraction and catalytic oxidation of off-gases. Isolation technologies include the demonstration of innovative soil caps, the *in situ* emplacement of soil grouts for verification, and the enhancement of natural soil moisture migration barriers.

All of the characterization technologies currently funded by the MWLID have been demonstrated. Remediation technologies will be demonstrated in the near-term. Several technologies, most notably the flexible membrane lining system (SEAMIST™) and the directional drilling capabilities (Ditch Witch™), are, or soon will be, commercially available.

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Organics in Soils and Ground Water at Non-Arid Sites

This integrated demonstration program is developing, demonstrating, and comparing technologies for remediation of volatile organics (e.g., TCE, PCE) in soils and ground water at non-arid DOE sites. The demonstration provides for technical performance comparisons of different available technologies at one specific site, based on cost effectiveness, risk reduction effectiveness, technology effectiveness, and general acceptability. Specifically, the demonstration involves characterization, off-gas treatment techniques, and other technologies associated with the remediation of soils and ground water contaminated with volatile organics. The demonstration also is designed to establish control and performance prediction methods for the individual technologies so they can be scaled up for full-scale remediation programs. Technology transfer to governments agencies and the industrial sector is a critical facet of the DOE demonstration program.

The technology emphasis for this integrated demonstration is *in situ* remediation because it has tremendous advantages over above-ground treatment. *In situ* remediation technology has the potential to be more effective in less time at a reduced cost and also had the benefit of minimizing worker exposure. Three *in situ* remediation systems have been or will soon be demonstrated: (1) *in situ* air stripping or air sparging, (2) *in situ* bioremediation, and (3) *in situ* heating (ohmic [six phase]) and radio frequency.

Directional well drilling, developed by the petroleum and utility installation industries, provides a tool to improve access to the subsurface for characterization, monitoring, and remediation. A full-scale field demonstration

using horizontal wells in combination with *in situ* air stripping (air sparging) has been conducted at the Savannah River site as part of the Integrated Demonstration Program. Two horizontal wells were installed along an abandoned process sewer line that is known to have leaked TCE and PCE. One well, installed below the water table and within the contaminated zone, was used for injection of air. The second well, installed above the water table, was used as a vapor extraction well. The system was demonstrated for 20 weeks. A total of 16,000 lbs. of chlorinated solvents was removed from the test site during the period.

Characterization technologies already demonstrated include depth-discrete soil and ground water sampling, cone penetrometer with real-time analytical capabilities, and nucleic acid probes for microbial characterization.

Monitoring technologies that have been demonstrated include geophysical tomography, fluid flow sensors, fiber optic chemical sensors, real-time field analytical methods, and multi-level vadose zone and ground water samplers.

Off-gas treatment technologies such as photocatalytic oxidation, catalytic oxidation, biotreatment, ion beam oxidation, steam reforming, membrane separation, and UV oxidation also are to be demonstrated.

General Site Information

This demonstration program is being conducted at DOE's Savannah River Site in Aiken, South Carolina. The Savannah River Site is located on the upper Atlantic Coastal Plain. The site is underlain by a thick wedge of unconsolidated

Tertiary and Cretaceous sediments that overlay the basement, which consists of pre-Cambrian and Paleozoic metamorphic rocks and consolidated Triassic sediments. Ground water flow at the site is controlled by hydrologic boundaries: flow at and immediately below the water table is to local tributaries; and flow in the lower aquifer is to the Savannah River or one of its major tributaries. The water table is located at approximately 135 feet. Ground water in the vicinity of the process sewer line contains elevated concentrations of TCE and PCE to depths of greater than 180 feet.

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Volatile Organic Compounds at Arid Sites

This integrated demonstration program will develop and compare technologies for removal/destruction of volatile organics (e.g., TCE, PCE) in arid sites. Control and performance prediction methods must be applicable to arid zones or environments with large vadose zones. The program will cover all phases involved in an actual cleanup, including all regulatory and permitting requirements, expediting future selection and implementation of the best technologies to show immediate and long-term effectiveness. The demonstration provides for technical performance comparisons of different available technologies at one specific site based on cost effectiveness, risk reduction effectiveness, technology effectiveness, and applicability.

Technologies in this integrated demonstration include steam reforming, supported liquid membrane separation, membrane separation, *in situ* bioremediation, *in situ* heating, and *in situ* corona destruction. The demonstration also involves development of field screening and real-time measurement capability and enhanced drilling, such as sonic drilling.

General Site Information

The site for this demonstration program consists of about 560 square miles of semi-arid terrain at DOE's Hanford Reservation. The test location contains primarily carbon tetrachloride, chloroform, and a variety of associated mixed waste contaminants. About 1,000 metric tons of carbon tetrachloride were discharged at waste disposal cribs between 1955 and 1973. Chemical processes to recover and purify plutonium at Hanford's plutonium finishing plant resulted in the production of actinide-bearing waste liquid. Both aqueous and organic liquid wastes were generated, and routinely discharged to subsurface disposal facilities. The primary radionuclide in the waste streams was plutonium, and the primary organic was carbon tetrachloride.

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Underground Storage Tanks

The Underground Storage Tank Integrated Demonstration (UST-ID) was created in February 1991 to develop alternatives to current baseline methods for remediating underground storage tanks (USTs). Where technology gaps exist, the UST-ID is developing extensions to current baselines and where uncertainties exist, the UST-ID is developing improvements.

All technologies are being developed from a systems perspective. For example, a state of the art sensor for characterizing tank waste is relatively useless without a way to place it in the tank. The characterization system being developed by the UST-ID therefore includes a deployment system as well as instrumentation and data validation tools.

Currently, the UST-ID is pursuing technologies in four fields:

- Waste Characterization
- Waste Retrieval
- Waste Separation
- Low-level Waste (LLW) Form

These are grouped into two general areas with complementary technical disciplines in each. The first blends characterization and retrieval using an arm-based manipulator system. The retrieval portion is made up of technologies being developed by the UST-ID and the Robotics Integrated Program (also within EM-50). The second group combines tank waste separations (or pretreatment) technologies with LLW form development.

Characterization/ Retrieval Technologies

Characterization:

Tank waste constituents range from sodium nitrates to transuranics. The waste has three forms: supernatant (liquid), sludges, and saltcake that can be as hard as cement. Radiation dose rates range from a few 100 mR/hr to 5,000 R/hr. The remediation task is complicated by significant uncertainty regarding the nature of the waste in a single tank. Characterization has traditionally been limited by high analytical costs and an inability to obtain data from many points in the tanks. Hence, technology development has focused on sensors that will decrease analytical time and generate a means for deploying sensors inside the tank.

Technical direction of the UST-ID in characterization is focused during FY 1993 on spectrographic demonstration in a hot cell using actual waste core samples. The primary technologies currently under development and review are the Laser Raman Scattering Spectroscopy and the Acoustic-Optic Tunable Filter Spectroscopy.

Retrieval:

This portion of the demonstration will focus on four major systems: early deployment system (EDS), light duty utility arm (LDUA), long reach arm (LRA), and end effectors.

The EDS is a simple vertical deployment device that can rapidly insert and retrieve a changeable set of sensors for surveillance, mapping, and inspection. They provide early access to a tank for testing systems and equipment that will be used on the LDUA. The LDUA is an articulated robotic arm used for surveillance, characterization, and limited sampling (e.g., 19-

L or 5-gal samples). It is designed to access a tank through a 12-in. riser, deploy vertically 40 ft, extend horizontally a minimum of 9 ft, be intrinsically safe, and carry with it a large variety of end effectors for characterization, surveillance, and limited sampling.

The LRA is a large articulated robotic arm for full scale waste retrieval. It will be designed to access tanks through a small riser (approximately 40 in.). It will deploy vertically 40 ft, extend horizontally a minimum of 45 ft., and position as much as several hundred to a thousand pounds of equipment. It will be capable of retrieving all three waste forms, as well as in-tank hardware. It is controlled by an operator or computer. Operator and public safety during retrieval is a key design component.

End effectors for the LRA are being developed to accomplish retrieval, characterization, surveillance, and sampling.

Separations/Low-Level Waste Technologies

Separations:

This portion involves a three-phased development approach corresponding to the types of UST waste to be treated: supernate, salt cake, and sludge. The first phase will focus on removing key constituents for supernate using ion exchange, calcination and other methods, and methods yet to be identified for removing selected radionuclides. The second phase will focus on treating salt cake by dissolution and will develop methods for separating solids and liquids. Lastly, sludge treatment will be developed in conjunction with the Efficient Separations and Processing Integrated Program.

To support the separation technologies, compact processing units (CPU) will be developed using a modular or distributed processing concept. These CPUs are an alternative to a large, permanent facility and are currently being

considered by DOE's Office of Waste Management (EM-30) as one means of deploying their initial separations processes. During FY 1993, the ion exchange technologies developed by the Savannah River National Laboratory will be evaluated for incorporation into the first fieldable CPU. The organic and nitrate destruction technologies will be initiated in late FY 1993. The CPUs will be designed and a system specification will be developed for competitive bid by industry.

During FY94, technologies for treating sludges developed by the Oak Ridge National Laboratory will be demonstrated and validated using the transuranium extraction (TRUEX) model. Sludge from the Melton Valley waste tanks will be washed, the supernate passed through ion exchange columns containing the resorcinol-formaldehyde resin in development at Savannah River. The sludge will be treated with a TRUEX process, and the results will be compared to the predictive model for TRUEX, supported by the Argonne National Laboratory.

The LLW form development will focus on testing two alternatives to the current disposal form for low-level waste (grout): nitrate to ammonia and ceramic (NAC) and polyethylene. The NAC process destroys nitrates and produces a ceramic LLW form in one process. The resulting ceramic can be sintered, which would destroy all organics by the high heat added during the final phase. The polyethylene process takes a dry waste stream and encapsulates it into a solid polyethylene matrix that can be extruded into the desired form.

General Site Information

The technologies developed in the UST-ID program will be used in remediation actions at five participating DOE sites: Hanford, Fernald Idaho, Oak Ridge, and Savannah River. The five sites began operations between 1943 and the early 1950s. They originally supported nuclear fuels production, operations, and research programs as part of the development of

nuclear weapons subsequent to World War II. Most of the site missions have evolved from war production to peaceful uses of nuclear power, research and development, and environmental cleanup.

A variety of processes were used to produce nuclear fuels at these sites. Most UST waste was generated by the processes used to separate nuclear fuels from other components. In the tanks, separation chemicals mixed with the fission and decay products generated in the initial production step. Early separation processes generated high concentration waste. Modern processes were designed to minimize these waste concentrations.

The major emphasis of the UST-ID is the single-shell storage tanks (SSTs) located at the Hanford site, located in the southeastern section of Washington State near the cities of Richland, Kennewick, and Pasco. The Hanford site has operated since 1943 with a primary mission of producing plutonium isotopes. Plutonium was produced by irradiation of enriched uranium in eight nuclear reactors located along the Columbia River. The plutonium was separated from the remaining uranium and fission products by chemical processes. It was then sent off site for further purification.

The waste generated by the different chemical separation processes has been stored in 177 USTs for future retrieval and treatment for final disposal. There are eight UST design types ranging in age from six to 49 years. Of the 177 USTs, 149 are of a single carbon steel shell with a reinforced concrete shell. The remaining 28 have dual carbon steel liners and range in

capacity from 208 to 3,785 m³ (55,000 to 1 million gal). Approximately 225,000 m³ (59.4 million gal) of high-level waste is stored in USTs. All of the waste is alkaline with a large percentage of sodium nitrate and nitrate salts and metal oxides. The principle radionuclides include ²³⁵U, ²³⁸U, ²³⁹Pu, and the uranium fission products ⁹⁰Sr and ¹³⁷Cs, as well as their decay products.

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Uranium Soils

The objectives of this integrated demonstration are to:

- Demonstrate advanced technologies to decontaminate uranium-contaminated soils;
- Demonstrate advanced technologies for field characterization and precision excavation;
- Demonstrate a system of advanced technologies that will work effectively together to characterize, excavate, decontaminate, and dispose of remaining wastes for uranium-contaminated soils; and
- Provide a transfer of these technologies into DOE restoration programs and the private sector.

The demonstration is expected to be conducted over five years. The results will go directly into the Fernald Environmental Management Project (FEMP) remediation process. Community relations activities will be conducted as part of the integrated demonstration in conjunction with the community relations activities currently ongoing under the FEMP CERCLA Program.

The integrated demonstration focuses on more than just the decontamination process. It has been organized to focus in six key areas:

- Characterization
- Excavation technologies
- Decontamination processes
- Secondary waste treatment
- Performance assessment
- Regulations

The demonstration provides for technical performance comparisons of different available technologies at one specific site based on cost effectiveness, risk reduction effectiveness, technology effectiveness, and general applicability. Enhanced site characterization and precise excavation technologies will be combined with advanced uranium soil decontamination processes to produce a technology system for use at the FEMP and throughout DOE for similar contamination cleanups.

In August and September, 1992, the following field screening characterization technologies were demonstrated at DOE's Fernald site:

- Surface and subsurface gamma spectroscopy.
- Mobile laser ablation inductively coupled plasma-atomic emission spectroscopy.
- Beta scintillation detector.
- Long-range alpha detector.

The D&D and the Incinerator areas were characterized using these technologies. In addition, the standard grab sample and laboratory analysis were evaluated. The results of the technologies generally were consistent, particularly at higher contamination, but there was considerable scatter in the data.

The demonstration illustrated the importance of interpreting the data in relation to regulatory cleanup limits. Improvements for field screening, as well as modifications for conveyor belt application, are being made to the techniques as a result of the demonstration findings. In addition, a cost/benefit analysis is

being conducted on the application of these techniques.

Analysis of soil samples is aimed at characterizing the chemical and physical properties of both the soils and uranium wastes. The tests are concentrating on defining the basic chemistry and mineralogy of the soils, size fractionation of the soils, uranium/soil fractionation characteristics, leachability of the uranium wastes, physical characterization of the particulate and occluded uranium waste, and the speciation (oxidation state, chemical structure, mode of binding) of uranium and uranium/organic mixtures in the Fernald soils.

Analyses have shown that the uranium exists primarily in particulate form. It is associated with the sand and silt fractions of the soil, but some samples also have uranium in the clay fraction. More than 80 percent of the uranium is in the hexavalent oxidation state. In general, hexavalent uranium has greater solubility than uranium in other oxidation states. Thus, strong oxidizing agents may not be necessary as part of a chemical remediation scheme.

Removal of uranium from heavy textured soils by conventional soil washing processes is ineffective because of the sorption of uranium on the high silt and clay content of these soils. A chemical extraction technique, one that selectively extracts uranium without causing serious physiochemical damage to the soils, is required. Treatability tests currently are being conducted using a number of promising technologies.

General Site Information

This integrated demonstration is being conducted at the Fernald Site, where uranium is the principal soil contaminant. The Fernald Site is located on 1,050 acres near the Great Miami River, 18 miles northwest of Cincinnati, OH. Established in the early 1950s, the production complex was used for processing uranium and its compounds from natural uranium ore

concentrates. As the primary production site for uranium metal for defense projects in the past, the facility was key to national security.

Following discontinuation of production at Fernald in 1989, environmental restoration became the mission of the site. During the 38 years of operations, the soils at the production area received varying amounts of uranium contamination resulting from accidental spills and emissions.

The technical strategy adopted by the CERCLA program is to divide the site into five distinct units:

- CRU1 — Waste pits 1-6, Clearwell and Burn Pit.
- CRU2 — Other waste units (fly ash pile/solid waste landfill).
- CRU3 — Production area.
- CRU4 — Silos 1, 2, 3, and 4.
- CRU5 — Environmental media.

Site soils are composed of clays, sands, and silts in widely varying proportions. The chemical and physical form of the uranium contamination varies with location and soil type.

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Borehole Slurry Extraction

The borehole miner was developed about 10 years ago to remotely extract a finite ore body with minimal environmental disturbance. Although developed specifically as a mining tool, the concept would be equally applicable to extracting contaminated material, such as might be present under a leaking fuel tank or surrounding a contaminated well.

Successful prototype mining tests have been conducted on uranium ore, oil sands, and phosphate ore. Because system operation depends on reducing the material to a pumpable slurry *in situ*, it is applicable to sandstone, soil, or clay-like sediments. In most cases, material to be removed for contamination remediation would be of the proper consistency.

The system operates through a single borehole, which extends down through the material to be extracted. Prototype tools have been constructed to fit into hole diameters of 6 to 12 inches. One or more water jet nozzles direct cutting streams radially from the tool to erode an underground cavity, roughly cylindrical in shape. The slurried material settles toward the bottom of the cavity where it is pumped to the surface by means of an eductor (jet pump), which is integral with the tool.

On the surface, the slurry is treated to remove the values. This is usually preceded by a dewatering step involving settling ponds and thickeners. In a remedial operation, it would be at this stage that the material would be decontaminated.

After treatment, the waste material (or clean decontaminated material) can be pumped back into the cavity by conducting the borehole

mining operation in reverse. Backfilling the cavity in this manner prevents surface subsidence. In a series of phosphate mining tests conducted in St. Johns County, Florida, a total of 1,700 tons of phosphate ore was extracted from a bed about 20 feet thick at a depth of about 250 feet. The underground cavity had a diameter of 30 to 40 feet, and production rates in excess of 40 tons/hr were achieved. Cavities were backfilled as part of the tests, and subsequent topographical surveys showed negligible subsidence.

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Characterization and Treatment of Contaminated Great Lakes Sediments

The Contaminated Great Lakes Sediments Metals Characterization and Treatment project is being performed under an Interagency Agreement between the Bureau of Mines (Bureau) and the U.S. Environmental Protection Agency (EPA). Work commenced in April 1990 by the Bureau's Minerals Separations research group at the Salt Lake City Research Center (SLRC).

The project has been conducted in cooperation with the Engineering-Technology Work Group in the Assessment and Remediation of Contaminated Sediments (ARCS) program. It is designed to investigate common mineral processing technologies as removal or remediation alternatives for contaminated sediments.

The Bureau's contribution to the ARCS program has been to evaluate the application of mineral processing (or physical separation) technologies for removal of low levels of contamination from large volumes of sediment. Physical separation techniques are widely used in the mining industry to recover valuable minerals or metals from ores. Methods such as size classification, magnetic separation, gravity separation, or froth flotation, collectively known as mineral processing, can be applied in some cases to separate contaminants from the bulk of polluted sediment. Since these methods are economically applied on a very large scale to ores of low value-to-mass ratio, they are among the least expensive separation processes in modern industry. The objective is to reduce the volume of contaminated material that requires more expensive treatment by concentrating the contaminants, in the same way an ore is beneficiated. For this reason, the term

"pretreatment" is used to indicate that some smaller amount of material will require further decontamination.

In the Characterization and Treatment project, the SLRC has studied sediments received from three Great Lakes priority areas of concern: Buffalo River, NY, on Lake Erie; Indiana Harbor-Grand Calumet River, IN, on Lake Michigan; and Saginaw River, MI, on Lake Huron. The sediment samples contain both organic and inorganic contamination.

Bench-scale testing by the Bureau of Mines has identified situations where considerable remediation cost savings may be realized by using mineral processing pretreatments. Among the most promising are grain-size-separation technology to separate contaminated silt and clay from relatively clean sand, and froth flotation to separate organic contaminants from the sediment.

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Solid/Liquid Separation

The disposal of contaminated sediments in an impoundment can create unique long-term disposal problems. When the impoundment becomes full, the material has to be loaded, usually with a dragline, and transported to an approved disposal facility. Suspended sediments also can require days and even months to settle so that the clean water can be safely discharged or recycled.

The dewatering system consists of a solid waste recovery system which separates solid from liquid, using a waste slurry as a feed material. The feed material is continuously injected with a known quantity and specific type of synthetic degradable polymer (usually a polyacrylamide) which flows through a designed pipe delivery system. This pipe serves as a mixing system for the polymer and feed slurry to produce flocculated material of sufficient size and strength while using the least quantity of polymer possible. The flocculated material passes over a series of properly sized slotted screens that retain the flocculated material and allow the "clean" water to pass through. These "static screens" are inclined at a fixed angle to maximize flow capacity and screen capture of solids content. The solid waste then can be easily transported to an approved disposal facility instead of being disposed of in impoundments which can leak into the ground water and require periodic cleaning out, resulting in a rehandling of the material.

Wastes often associated with mining operations are infamous for their toxic and/or voluminous quantity when compared to waste from any other industry. A field test unit (FTU) to remove the solids from a wastewater slurry was demonstrated in 1992 at mining sites in

Birmingham, Alabama, and Manassas, Virginia. This investigation was conducted on non-toxic fine waste slurries initially disposed of in impoundments, which were required to be emptied periodically. Feed flow rates for the FTU varied from 50 to 175 gpm. The solids content of the feed material varied from 2 to 17 percent. The dewatered solids exited the system at approximately 50 percent solids and continued to dewater. At the end of 24 hours, the material has a solid content of approximately 70 percent and was still yielding clean water.

The cost of using the polymer ranged from \$0.50 to \$0.60/ton of dry solids produced when the polymer is purchased in bulk. The polymer cost is the most significant cost of the system. Except for the pumps used to deliver the feed and polymer, the remaining system relies on gravity flow through the circuit to accomplish separation.

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Solid/Liquid Separation

Dewatering of slurries has been successfully accomplished by the proper use of polymers in flocculating the fine particulate matter suspended in mineral processing streams. The U.S. Bureau of Mines entered into a cooperative research effort with the U.S. Army Corps of Engineers for the purpose of testing the applicability of flocculation technology to the removal of suspended particulates resulting from dredging of sediments from navigable waterways.

The process consisted of feed material from the barge being pumped through a 4-inch line to a centrifugal pump and exiting through a 4-inch PVC delivery system. A 1,000-gal. fiberglass tank was used to mix the polymer concentrate. The polymer was pumped through a 1-inch line using a variable speed moyno type pump and introduced to the 4-inch feed line prior to passing through a 6-inch-by-2-foot static mixer. The polymer/feed material slurry traveled to the clarifying tank where the flocculated material settled to the bottom, and allowed "clean" water to exit the overflow.

A pilot-scale flocculation unit was operated on-site at the Corps' confined disposal facility in Buffalo, New York. A loaded barge containing sediments dredged from the Buffalo River was delivered to the confined disposal facility for flocculation studies. Contaminated sediments were pumped from the barge to the flocculation unit. Tests were conducted using polymer concentrations of 0.01, 0.02, and 0.03 percent, pumped at variable flow rates. Feed from the barge consisting of about 1.5 percent solids was pumped through the unit at about 200 gpm. The NTU values of the discharge water ranged

from 12 to 17 with the underflow discharge containing about 31 percent solids.

Costs associated with the polymer requirements were calculated from the original cost of the polymer when purchased in bulk (\$0.50/lb.). Processing of 1,000 gal. of 1.5 percent contaminated river sediments required less than \$0.01 of polymer.

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Treatment of Copper Industry Waste

The primary copper industry is one of the largest generators of mining and mineral-processing wastes. While most of the generated waste materials pose no threat to the environment, some may be subject to regulation under Subtitle C of RCRA because of their toxic corrosive characteristics. The wastes may include slags, sludges, dusts, and liquids. They often contain toxic and heavy-metal contaminants as well as metal values which are presently discarded.

The Bureau of Mines, at the Salt Lake Research Center, is developing a technology to recover valuable components from these materials and stabilize the toxic constituents in environmentally-safe forms. Recent investigations have been directed toward the co-processing of two waste streams: (1) an arsenic-laden smelter flue dust; and (2) the acidic bleed solution from an electrolytic copper refinery. Acid in the refinery waste is used to solubilize the metals in the flue dust, and valuable components are subsequently recovered using hydrometallurgical techniques.

The vitrification of arsenic sulfide, removed from refinery effluents and acid-plant blowdown solutions, in a dense, non-reactive, glass-like material has also been studied in an effort to provide an environmentally safe option for disposing of arsenic.

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Vapor Extraction and Bioventing Design Gasoline in Soil and Ground Water (*In Situ* Treatment)

To date, the practice of vapor extraction has not included the application of air flow and vapor transport models to guide data collection techniques for site characterization and to define optimal extraction and injection well locations. Quantification of the flow patterns associated with a vapor extraction design will lead to rational estimates of clean-up criteria and system performance.

The U.S. Geological Survey (USGS) ground water flow simulator MODFLOW has been adapted to perform airflow simulations. This airflow simulator, referred to as AIRFLOW, has been coupled with an optimization algorithm to formally predict the location and pumping rates for wells to achieve the best venting system design given the site geology. A vapor transport code is under development that will allow for the calculation of enhanced microbial degradation (bioventing) associated with the vapor extraction system.

The success of the model application fundamentally depends on the ability to characterize the air permeability in the unsaturated zone. Heterogeneity with respect to air permeability due to stratification of sediments and variable moisture content distribution must be considered for site specific application of the models. At the USGS gasoline spill research site at Galloway Township, New Jersey, field methods have been developed to determine the distribution of air permeability in the unsaturated zone. AIRFLOW has been successfully applied to quantify the flow paths for a bioventing design. A vapor concentration data base is being constructed for future

application of the vapor transport code for bioventing application.

General Site Information

Field research at the Galloway Township gasoline site began in 1988. The site is one of sandy sediments in the New Jersey Coastal Plain. Gasoline leaked from a small underground storage tank and contaminated shallow ground water. In addition to the venting and bioventing remediation study, an extensive investigation of natural attenuation mechanisms, including vapor transport and the natural rate of aerobic and anaerobic microbial degradation of hydrocarbons, is being conducted. The research team seeks to combine laboratory, field, and modeling techniques to develop practical methods for estimating the rates of contaminant movement and attenuation.

Contact

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Well Point Containment

There are numerous containment and leachate control methods in use today to prevent contaminants from reaching ground water. Each system, however, is dependent on site-specific conditions. Subsurface or french drains which typically consist of continuous lengths of perforated pipe placed in trenches excavated below ground water level is one method often used. In this application, contaminated ground water which flows under a natural or induced hydraulic gradient to the french drain is intercepted and conveyed to a sump or storage tank prior to wastewater treatment. When functioning properly, french drain systems are a cost-effective containment strategy where, at shallow depths, the subsurface permeability is high and there is an active hydraulic gradient.

Well point systems are another inexpensive and versatile technique used in controlling and containing leachate pollution. These systems can be used to alter the water table to facilitate construction, remove leachate for treatment, divert ground water around a contaminated area, or control the movement of a contaminant plume. Well point systems can consist of one or a series of production wells that intercept and withdraw contaminated fluids from saturated soils where the contaminated soils are then pumped to wastewater treatment or storage facilities.

A research project was undertaken by the U.S. Bureau of Mines to determine the effectiveness of a well point system in conjunction with a french drain for use in capturing impoundment leakage. The test site chosen was a chemical company waste impoundment which was leaking acidic waters containing elevated levels

of iron and lead. The impoundment was surrounded by a french drain system which had been previously installed to contain the leakage. As the metal-laden, acidic leakage from the impoundment mixed with uncontaminated ground water in the french drain, the pH of the contaminated plume increased with the resultant precipitation of the dissolved metals. The precipitation of metals tended to clog the french drain and frequent cleaning was necessary to maintain effectiveness. The well point system was strategically placed between the leaking impoundment and the french drain to intercept the contaminated ground water and allow the french drain to act as a cut-off mechanism, thus preventing the encroachment of uncontaminated ground water.

Initially a series of 235 well points were placed along the northern side of the impoundment between the impoundment and the french drain. A network of monitoring wells was installed near the perimeter of the impoundment to assess changes in the ground water quality. Monitoring wells were placed in three general areas: in the string of well points, in the area between the well points and the french drain, and outside the french drain.

Samples were collected periodically for 140 days from each of the monitoring wells to evaluate the effectiveness of the well point system. Lead levels remained relatively constant throughout the test period for monitoring wells located in the string of well points. Once the pumping began lead levels in the monitoring wells between the well points and the french drain declined. Lead levels declined throughout the test period indicating

the leakage had been effectively contained. A corresponding rise in pH was noted in the fluids captured by the french drain from a low pH of 2.8 prior to pumping to a high of 3.7 at the end of the test period.

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APPENDIX C

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Programs:

Robert Bartell
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SMALL BUSINESS INNOVATIVE

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Kathy Ann Kurke
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U.S. DEPARTMENT OF ENERGY

RESEARCH PROGRAMS:

Technology Integration Division
Office of Technology Development
301/903-7911

DEMONSTRATION PROGRAMS:

Technology Integration Division
Office of Technology Development
301/903-7917

SMALL BUSINESS TECHNOLOGY INTEGRATION:

Technology Integration Division
Office of Technology Development
301/903-7449

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENTS

(CRDAs):
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Office of Technology Development
301/903-7900

U.S. ENVIRONMENTAL PROTECTION AGENCY

GENERAL INFORMATION:

Site Cleanup Technologies:
Technology Innovation Office
703/308-8800

**Cleanup Technologies for Sites
Contaminated with Radioactive Material:**
Office of Radiation Programs
202/233-9350

RESEARCH PROGRAMS:
General Information:
Risk Reduction Engineering Laboratory
513/569-7418

Grants Information:
Office of Exploratory Research
202/260-7473

DEMONSTRATION PROGRAMS:
General Information:
Superfund Innovative Technology Evaluation
(SITE) Program
513/569-7696

Programs:
SITE Emerging Technologies Program
513/569-7665

SITE Demonstration Program
513/569-7891

SITE Monitoring and Measurement
Technologies Program
702/798-2432

SITE Technology Transfer Program
513/569-7562

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Innovative Remedial Technologies Information Collection Guide

INSTRUCTIONS FOR SUBMITTING AN ABSTRACT

The following is the suggested format for submitting a remedial technology abstract for inclusion in the Synopses of Federal Demonstration Projects for Innovative Hazardous Waste Treatment Technologies. The format has been divided into five sections, each designed to gather specific information for the abstract. These five sections are:

- Technology Description;
- Technology Performance;
- Remediation Costs;
- General Site Information; and
- Contacts.

Although a form has been provided for your convenience, you may submit abstract information without use of this form, or you may attach additional information to this form, as necessary. If possible, this information should be presented in the same order as it appears in this example. It is understood that many abstracts will contain only partial information, as the projects are still being tested; however, please submit as much information as possible, as this will assist others in better understanding the innovative treatment technology.

Abstract information, comments, and questions relating to this project should be directed to:

Daniel M. Powell
Technology Innovation Office
U.S. Environmental Protection Agency
401 M Street, S.W., OS-110
Washington, D.C. 20460

Innovative Remedial Technologies Information Collection Guide

1. TECHNOLOGY DESCRIPTION

Type of Technology and Exact Technology Name (e.g., Bioremediation: Aerobic Biodegradation of Trichloroethylene):

Waste Description (e.g., PCB's in sludge):

Media Contaminated (e.g., groundwater, soil, surface water):

Targeted Contaminants and Concentrations (e.g., PCB's at 500 ppm):

Description of Treatment Process:

Description of Preliminary or Secondary Treatment, If Any:

Summary of Monitoring Results (e.g., air emissions, waste water discharge):

Limitations of Technology (e.g., weather, soil type, depth of water table):

2. TECHNOLOGY PERFORMANCE

Overall Attainment of Clean-Up Goals (e.g., residual contamination):

Summary of Data Used to Evaluate Technology Effectiveness:

Treatment Capacity (e.g., gallons per day, tons per day):

Types and Amounts of Residual Wastes (e.g., ash, steam, wastewater):

Ultimate Disposal Options (e.g., landfilling of ash):

Malfunctions and Disruptions Encountered:

Interfering Compounds:

Description and Length of Future Maintenance and Monitoring Required:

Additional Comments:

3. REMEDIATION COSTS

Total cost of Remediation Project, Not Including Site Investigations: _____

Cost of Remediation Project per Unit of Waste,
Not Including Site Investigations (e.g., dollars per ton): _____

Design Costs: _____ Time Required for Design: _____

Site Preparation: _____

Equipment Costs: _____

Start-up and Fixed Costs (e.g., transportation, insurance, shakedown, training): _____

Labor Costs (e.g., salaries and living expenses): _____

Consumables and Supplies (e.g., chemicals, cement): _____

Utilities (e.g., fuel, electricity): _____

Effluent Treatment and Disposal: _____

Residuals/waste shipping and handling: _____

Analytical Services: _____

Maintenance and Modification: _____

Demobilization: _____

Projected Costs of Future Maintenance and Monitoring per Year: _____

Estimated Time Required for Operation and Maintenance: _____

4. GENERAL SITE INFORMATION

Site Name:

Site Location:

Time Period Covered by the Project:

Scale of Project (i.e., treatability study, bench scale, pilot test, field demonstration or full-scale remediation):

Site Characterization Data (to the extent that it affects the treatment process):

Volume of Area Contaminated:

Facility's Current and Previous Uses:

5. CONTACTS

Facility Contact:

Remedial Action Contractor:

Contractor Contact:

Other Contacts:

Suggestions

If you have comments on the usefulness and clarity of this publication, or if you have suggestions on how to improve it, please make a note on this page. This is a self-addressed mailer — just add postage, and drop it in the mail.

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